University of Nottingham

Assessing the Impact of Facility Layout Design over the Process Productivity and Costs

José Sáenz Poch

MSc Operations Management

Assessing the Impact of Facility Layout Design over the Process Productivity and Costs

By

José Sáenz Poch

2009

A dissertation presented in part consideration for the degree of MSc Operations Management

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, Dr. Christos Braziotis, whose encouragement, guidance and support enabled me to develop this dissertation. Without his help this research could not have been done.

I would like to thank the University of Nottingham for providing me the opportunity to study in the UK. Special thanks to the MSc Operations Management teachers for their unconditional support.

I would like to thank the company Urupanel for the opportunity to study their case. Without their support and commitment the dissertation would not have been completed.

Finally, I would like to dedicate this dissertation to my beloved family who have given me never-ending love and supported me through this entire dissertation, and even more important throughout my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Growing variability of markets has helped facility layout design emerge as an improvement tool for companies to facilitate their internal operations and cope with the increasing uncertainty. This is the case of many industries, especially commodities industries.

This particular study focuses on the impact of facility layout design over the process productivity and costs. The research was based on a single case study the company Urupanel. This company is located in Uruguay and their main product is plywood. The company was chosen mainly for the possibility to access their information and visit their facility.

The study analysed the existent literature regarding this topic and provided a discussion of the different arguments that are proposed by authors. Then the analysis of the company facility layout design is approached. Furthermore, improvements regarding the design of their facility layout design are proposed.

This paper concludes that the impact of facility layout design is greater on cost reduction rather than on process productivity. In addition, the facility layout factor with the greatest contribution to these impacts is the material handling factor.

CHAPTER 1: Introduction

Facility layout design has been discussed over many years demonstrating to be a timeless topic of concern. As argued by Heizer and Render (2008) the layout design of a facility has many implications in the organisation's competitive priorities regarding capacity, processes, flexibility and costs. These implications have grown the interest on this subject especially due to the necessity of improvement of the competitive priorities in order to deal with the uncertainty of external factors to the enterprise.

The interest on this subject has produced extensive discussions over the objectives and scope of it. This study will analyse the different discussions relevant to the subject and provide findings on the implications of facility layout design in a company. Furthermore, the plywood industry is analysed as one of the industries that have been affected by external factors and are turning their focus towards their operational problems. The next two sections introduce two focuses regarding this subject: theoretical and wood and plywood industry focus.

1.1 Theoretical focus

Many authors have approached facility layout design in order to assess the impact on different aspects of companies. The discussion has included different topics of this subject. The main topics can be divided into: the objectives, the approaches and the impact on different parameters of a company such as productivity and costs. Even though these topics can be studied separately the interaction between them is constant.

This interaction begins with the establishment of the objectives. These objectives may vary according to the authors and relevant discussion upon them is broad up. The objectives will be the most important influence on the development of different approaches to cope with the issue of facility layout design.

Having different perspectives towards the objectives will produce diverse influences to the development of approaches. As a result different approaches to handle facility layout design are developed in order to meet the different objectives. Thus, dissimilar outcomes may arise from the approaches that will impact on the companies' parameters.

Having a strong discussion over different topics among authors encourages the study of the subject to prove the different point of views. The next section highlights the wood and plywood industry focus and further below in this study the research aim and question are proposed.

1.2 Wood industry and plywood industry focus

Nowadays, with the dramatic fall in commodity prices, producers are operating with low profit margins. According to Caballero *et al.* (2008) the decline in global growth leads to a decumulation of inventories and a rapid collapse in commodity prices. The consumption, production, and prices of the forest product industry will decrease to the lowest levels in at least a generation, even reach levels not seen in living memory (Fuller, 2009). The Table 1.1 illustrates the reduction in the wood product industry.

Table 1.1. Wood products consumption. ***Source:*** **Fuller (2009).**

WOOD PRODUCTS CONSUMPTION (Domestic + Net Exports)								
Million Cubic Meters								
		2006	**2007**	**2008**		**2009**		**2011**
LUMBER								
North America		178.5	158.3	136.8		121.9		168.3
Europe		104.4	109.4	97.5		89.0		98.0
China		30.3	34.2	34.0		30.8		35.5
TOTAL		313.2	301.9	268.3		241.7		301.8
PLYWOOD								
North America		16.0	14.1	12.1		10.4		12.7
Europe		8.0	8.4	8.0		7.2		7.9
China		30.6	33.0	31.4		27.5		30.2
TOTAL		54.6	55.5	51.5		45.1		50.8
PARTICLEBOA RD								
North America		10.1	9.0	7.8		6.7		8.7
Europe		34.8	36.4	33.8		30.5		34.0
China		8.1	8.9	8.3		7.4		9.0
TOTAL		53.0	54.3	49.9		44.6		51.7
MDF/HDF								
North America		6.6	6.2	5.4		4.9		6.6
Europe		11.7	12.1	12.3		11.4		12.5
China		25.2	27.8	25.5		22.7		27.8
TOTAL		43.5	46.1	43.2		39.0		46.9
TOTALS								
North America		211.2	187.6	162.1		143.9		196.3
Europe		158.9	166.3	151.6		138.1		152.4
China		94.2	103.9	99.2		88.4		102.5
TOTAL		464.3	457.8	412.9		370.4		451.2

As shown in the Table 1.1, the plywood industry has suffered a drop in the consumption of approximately 4 million cubic meters from the year 2007 to 2008 and the prognostic does not look encouraging.

The United States is the second larger consumer of the plywood industry according to the Table 1.1. The two largest markets for plywood in the Unites States are the construction of new buildings and the totality of residential construction. This includes two markets: new construction and repair and remodelling. These two markets accounts for the 63% of the panel consumption (Spelter *et al.*, 2006). Having that much influence on the plywood market makes the industry very vulnerable to any fluctuations of the demand of this country. This occurred in the so called “subprime crisis”.

The "subprime crisis" started about three years ago involving primary the construction sector, especially the house market. Since 1991 the growth of house construction was increasing steadily and getting to its peak in 2005 with over 2 million new homes. Yet, this tendency was abruptly finished by the "subprime crisis" and in May 2008 the number of new homes was just 970,000, the lowest level since 1990s (Natural Resources Canada, 2008). Many plywood producer countries where affected due to this crisis. An example of these countries is the case of Canada reflected in the Figure 1.1. It is possible to appreciate how the exports of wood to the United States have suffered a dramatic fall.

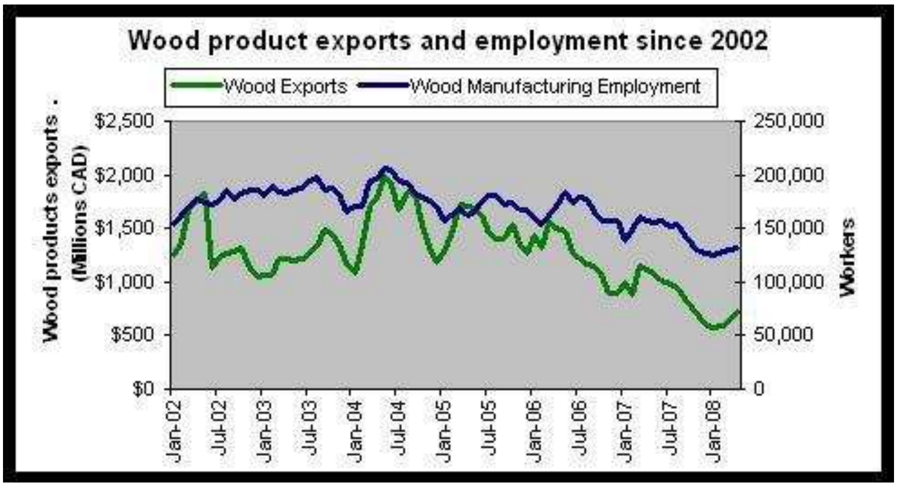


Figure 1.1. Wood product exports and employment since 2002. ***Source:*** **Natural Resources Canada.**

Figure 1.1 shows how the wood exports have followed a constant decrease over the months. The decrease of wood exports has also affected the wood manufacturing employment. This industry has suffered a major decrease reflected on the 135,000 workers approximately in January 2008 against the 200,000 workers in July 2004.

Considering the case of Latin America the scenario is not so different. Chile has suffered a reduction of 12.6% of the exports to the United States in the year 2008 in comparison to the previous year (Lignum, 2008). Furthermore, the prices of plywood have also been unstable in the last years as shown in the Figure 1.2.

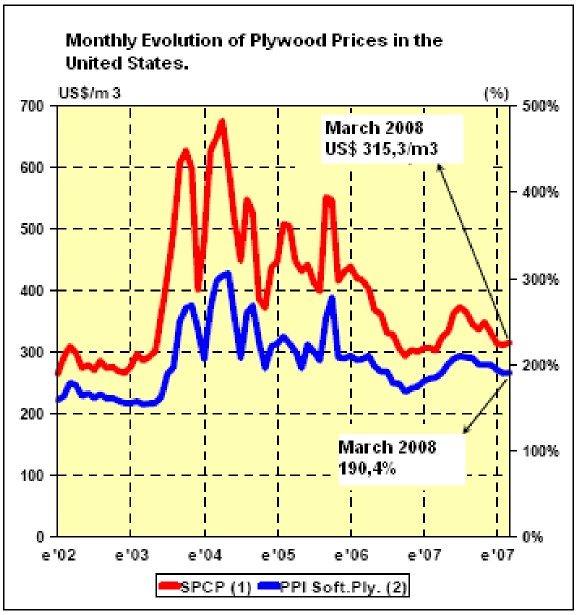


Figure 1.2. Monthly Evolution of Plywood Prices in the United States. ***Source:*** **INFOR.**

Even though plywood price had an increase in year 2007 over 2006, the future tendency of price does not look encouraging. Canada and Chile are only two examples of countries in the wood industry that have been affected by several crises. Having none or a small influence in the external factors to a company in the wood industry makes the internal issues arise as the only way to cope with this variation in prices and production.

Due to market fluctuations and uncertainty companies have become interested in the improvements of their internal aspects. That is why facility layout design has emerge as an essential tool to increase profit margins by directly reducing production costs not only in each commodity industry but also particularly in the plywood industry.

1.3 Research aim and objectives

The aim of this research is to evaluate the impact of facility layout design over the process parameters productivity and costs. In addition, the analysis implies the evaluation of two factors: plant layout and material handling. These factors have been widely considered in the different approaches developed over the years. The research question for this study is:

Which of the facility layout factors has a greater contribution over the process productivity and reduction of costs?

This research question is break down into subsidiaries questions to provide a comprehensive understanding of the implications of the facility layout factors. These questions are:

- Which is the impact of plant layout factor over the productivity and costs?
- Which is the impact of material handling factor over the productivity and costs?

Therefore, the objective of this research is to determine the most relevant factor in terms of process productivity and cost reduction. Moreover, the impact of the overall facility layout design is determined.

In order to develop the research question a case study will be introduced. In this case study the individual factors will be measured in the current state and improved if possible to assess the impact that they have over the company process productivity and costs.

1.4 Case study background

Urupanel was created in the year 2004 as an industrial project aiming to develop the forest industry in the north of Uruguay. This area was mainly focus on the raw materials business without any further processing of these materials. The idea of this company emerges due to the necessity of utilisation of the raw materials collected from the forest thinning which are mainly logs. The uses of the logs are extensive such as: production of furniture, medium density fibreboard, chips, plywood and others.

Even though the opportunities are extensive, the company focuses on the last one: plywood. This decision was mainly based on the previous experience of the members of the company on this industry.

In the year 2005 the construction of the plywood plant ends using the latest technology available. The first stage was design to provide a capacity of 60,000 m^3 of plywood annually. This capacity was reached on July of the year 2006. Even though this capacity was what they have planned, the growing demand encourages them to extend this capacity by starting a new stage of the plant. This stage increases the capacity to over 100,000 m^3 of plywood annually.
The completion of this two stages positions Urupanel as the first exporting company of plywood in the country of Uruguay and a pioneer in the technological development of the forest industry in this country. The investments made on the selection of the equipment, technology and the development of products were all orientated towards achieving a single goal: manufacturing the best product with the most competitive price in order to position Urupanel as a benchmark company in the international plywood industry.

1.5 Dissertation structure

The first chapter of this research aims to introduce the subject of facility layout design. A theoretical focus of this research is elaborated. This is followed by a wood industry and specially a plywood industry focus introducing the relevance that facilities layout design has achieved in this particular industry. Then the research aims and objectives are highlighted including the research question. After these the case study chosen, the company Urupanel, is presented with the main information about its background. Finally a summary of this chapter is included.

The second chapter of this research presents the literature review. The purpose of it is to have an academic review of the subject and understand the problems and solutions proposed, in order to provide a different point of view of the subject. In this chapter the facility layout objectives and the different approaches developed over the years are introduced. Furthermore, the relevant facility layout factors and their respective evaluation are included. Finally the reasons behind the research question emergence are highlighted.

The third chapter refers to the research methodology. Both qualitative and quantitative methods are explained as well as the sources of evidence that will be included in the study.

Also the data collection procedure is explained with the relevant techniques that will be used to gather the information about the case study.

In the fourth chapter the literature review exposed is analyzed regarding the case study chosen. The relevant data collected will be processed and then the different aspects of the facility layout design will be addressed. The results will be compared with what was established in previous research. Furthermore findings of the study and recommendations for the company are discussed.

The final chapter provides the conclusions of the research. In this section the main issues discussed are summarised. Furthermore, the limitations of this study and the implications for further research are expressed.

1.6 Summary

This chapter aims to introduce the subject of this study: facilities layout design. A theoretical focus is discussed highlighting the different discussions among this subject and the relevance this topic has acquired over the years.

Having this theoretical frame allows to discuss a particular focus: the wood and plywood industry focus. Examples of crisis that had affected this industry are mentioned as an important factor that triggers the necessity to focus on operational issues in order to cope with demand and price fluctuations.

The scope of facilities layout design is discussed in the next chapter having an emphasis on the factors involved in this subject. Moreover a case study is introduced in chapter 4 to contrast what is said in the literature and what happens in reality.

CHAPTER 2: Literature Review

2.1 Introduction

Many definitions have been established for facility layout design involving different elements of a company. Apple (1977) provides a structured definition by dividing it into two areas: plant layout and material handling. Even though he introduced this definition, contemporaries authors like Sarin *et al.* (1992) suggested a more holistic definition arguing that involves aspects such as flexibility, safety, ease of supervision, and others. In addition, Drira *et al.* (2007) suggested that machine, personnel, materials and everything that participates in the production of goods and services are involved in the facility layout design. Although the tendency over the years was to add different aspects into the definition, Tompkins *et al.* (2003) remarks that the integration between plant layout and material handling is particularly critical in the design of a new facility.

Tompkins *et al.* (2003) also discussed that facility layout design is an important area to focus regarding the improvement of productivity. In order to comprehend Tompkins' statement, it is of particular importance to understand the adequate definition of productivity. At these respect, Heizer and Render (2008) states that productivity is the ratio of outputs (goods and services) divided by the inputs (resources, such as labour and capital). Therefore, productivity is directly affected by the necessary resources to produce. The reduction of these resources is reflected in a decrease of the operating costs. Regarding the reduction of costs Tompkins *et al.* (2003) suggests that by having a better facility layout design the percentage of cost reduction could be increased at least to a range of 10% to 30%.

Moreover, Frazelle (1986) suggest that a significant cost saving can be achieved by reducing the material handling activities. Tompkins *et al.* (2003) agrees with this argument and takes one step forward in this issue through the quantification of the cost saving. They suggest that material handling can be attributed to a range of 20% to 50% of the manufacturing costs of a company.

Having that influence and impact on critical aspects of a company, facility layout design has emerged as a crucial decision process for companies regardless of the nature of business they are involved in. However, the impact of this tool has not been clearly established yet. Authors have suggested relationships between facility layout design and improvements in productivity without any quantification. Furthermore, cost reductions are attributed either to the material handling issues or the entire facility layout design. This lack of specification regarding the improvements as well as the area behind this improvement encourages the division of this subject into the previous definition established by Apple (1977): plant layout and material handling. These two areas will represent the facility layout factors of this study. Through the analysis of these factors it is intended to measure the impact of facility layout design over the process productivity and reduction of costs.

Sthahl (1990) defined plant layout as “the arrangement of work space which smoothes the way to access facilities that have strong interaction”. This definition was supported and specified by Francis *et al.* (1992) arguing that the layout involves the arrangement of different activities such as, departments, machines, workstations in the facility, taking into consideration the sizes and shapes of these activities. Furthermore, flow constitutes the heart of a plant layout and it is the path that every material or part takes in the plant during the manufacturing process (Meyers and Stephens, 2005).

On the other hand, material handling is “the art and science of moving, storing, protecting, and controlling material” (Tompkins *et al.*, 2003). Sule (2009) breakdowns this definition arguing that the movement of materials includes raw materials, work-in progress and final products between departments, workstations and storage locations. Sule (2009) means by work-in process the amount of units of the product that are on hold in the process to be further processed (Slack *et al.,* 2004).

As argued by Tompkins *et al.* (2003), Frazelle (1986) and others the impact of facility layout design over critical aspects of the company is important. However the contribution of the facility layout factors is not specified. That is why this study is focused on the impact of these factors over the process productivity and costs. This provides clarification of the impact of facility layout design over these parameters by specifying the contribution of these two factors.

2.2 Facility layout design objectives

As mentioned in the previous section, the scope of facility layout design includes critical aspects for a company. In order to deal with these aspects, several objectives have been attributed to facility layout design. Some of them are primary focused on the transformation of resources into products. Other objectives are focus on the organisation structure and people such as the provision of employee comfort and safety. Apple (1977) suggested the following objectives:

- Facilitate the manufacturing process.
- Minimize material handling.
- Maintain flexibility of arrangement and operation.
- Maintain high turnover of work-in-process.
- Make economical use of building cube.
- Promote effective utilisation of manpower.
- Provide for employee convenience, safety, and comfort.

Even though Apple (1977) proposed several objectives for the facility layout design problem, some authors did not agreed on some of these objectives and also add others to this list. Is the case of Francis *et al.* (1992) which agreed with all of the objectives proposed by Apple except for the maintenance of high turnover of work-in progress and with the facilitation of the manufacturing process. Instead, they proposed the minimization of overall production time.

Tompkins *et al.* (2003) agree on the effective utilization of resources such as equipment, people and space. However, they did not refer to the other objectives explained by Apple (1977). In addition they suggested other objectives such as the maximization of the return on investment for all the capital expenditures. Return on investment (ROI) represents the ratio between the net benefits and cost of an investment (Erdogmus *et al.*, 2004).

As well as with the impact of facility layout design over process productivity and costs, there are different opinions regarding the objectives. This contributes to the imprecision in the quantification of the impact of facility layout design over process productivity and cost reduction.

2.3 Facility layout design approaches

Many approaches have been developed to solve the facility layout design problem. These approaches can be classified as procedures, mathematical algorithms and software packages. The approaches are mainly focus on the two facility layout factors.

There are three main procedures as described by Tompkins *et al.* (2003): Reed's plant layout procedure, Muther's systematic layout planning procedure and Apple's plant layout procedure. The three procedures consist of a series of steps to follow in order to achieve an approximation of how the facility layout design would be established. As argue by Tompkins *et al.* (2003) the concepts introduced in these procedures are the foundation for many other approaches proposed. Reed (1961) suggests the following steps in his procedure:

1. Analyze the product or products to be produce.
2. Determine the process required to manufacture the product.
3. Prepare layout planning charts.
   3.1. Flow process, including operations, transportation, storage, and inspections.
   3.2. Standard times for each operation.
   3.3. Machine selection and balance.
   3.4. Manpower selection and balance.
   3.5. Material handling requirements.
4. Determine workstations.
5. Analyze storage area requirements.
6. Establish minimum aisle widths.
7. Establish office requirements.
8. Consider personnel facilities and services.
9. Survey plant services.
10. Provide for future expansion.

Reed (1961) argues that the most important steps are the ones involved in the preparation of layout planning charts. This step includes the analysis of the flow process, the standard times for each operation, machine selection, workers selection and material handling requirements. Although Reed's plant procedure was established, Muther (1973) developed a new procedure with some similar steps like the flow analysis and the space requirements that is shown in Figure 2.1.

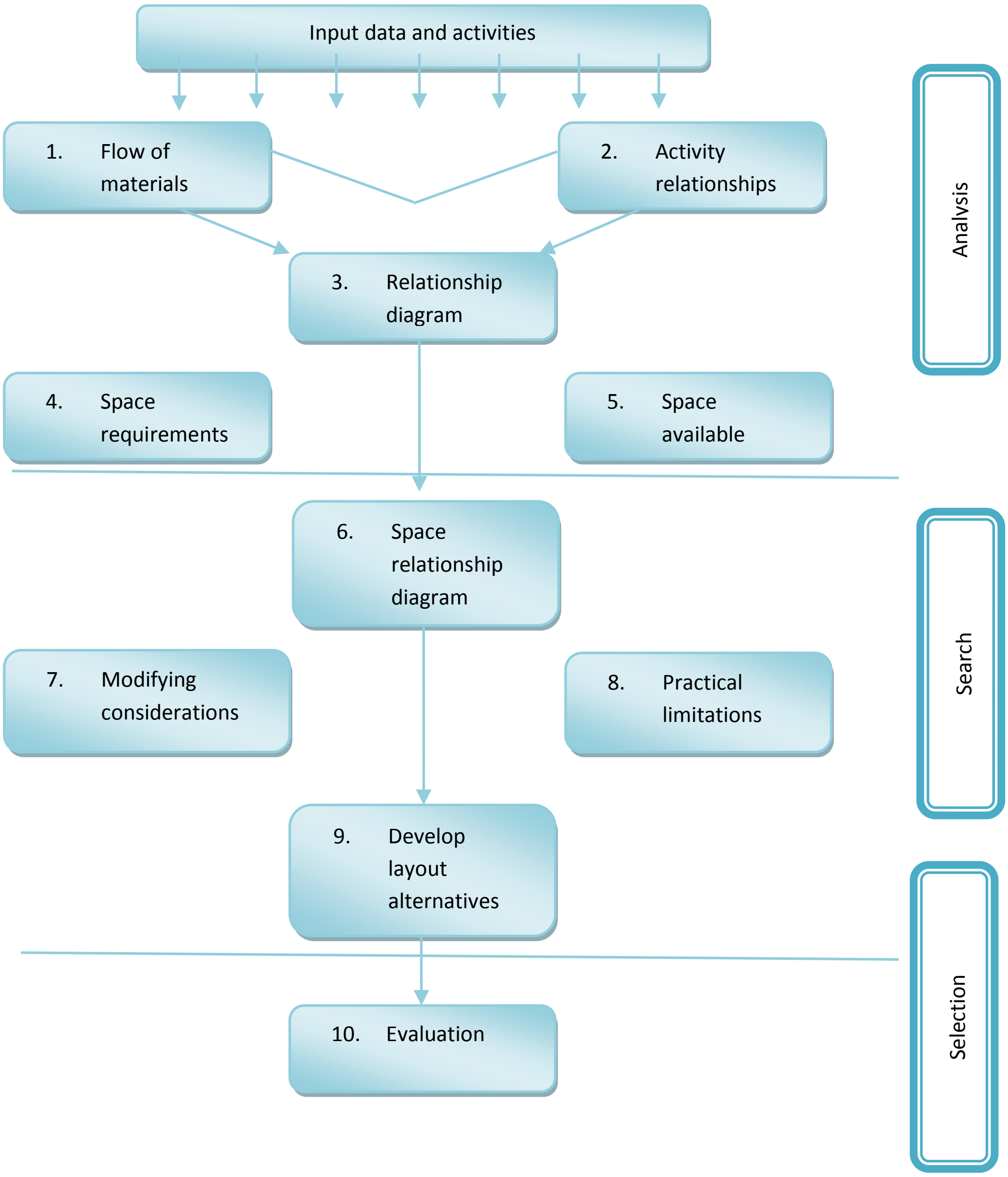


Figure 2.1. Systematic layout planning (SLP) procedure. ***Source:*** **Tompkins *et al.* (2003).**

Even though these two procedures were introduced, Apple (1977) proposed a new procedure with similarities and differences. He included other steps like the consideration of building types and the follow-up on the implementation of the layout. The steps of this procedure are:

1. Procure the basic data.
2. Analyze the basic data.
3. Design the productive process.
4. Plan material flow pattern.
5. Consider general material handling plan.
6. Calculate equipment requirements.
7. Plan individual work stations.
8. Select specific material handling equipment.
9. Coordinate groups of related operations.
10. Design activity relationships.
11. Determine storage requirements.
12. Plan service and auxiliary activities.
13. Determine space requirements.
14. Allocate activities to total space.
15. Consider the building types.
16. Construct master layout.
17. Evaluate, adjust, and check layout with appropriate persons.
18. Obtain approvals.
19. Install layout
20. Follow-up on implementation of the layout.

Apple (1977) suggests that the sequence of the steps is for guidance matters only, because as there is not two identical layouts there will not be two exact procedures. Probably will be some changes in the sequence produced by changes in the layout specifications.

Even though both Apple's and Reed's procedure include the material handling factor and that Muther's procedure does not include it, the systematic layout planning becomes the most widely used among companies and academics (Chien, 2004). This is the main reason to adopt the systematic layout planning, with some modifications, in this study. This procedure will allow the individualisation of the facility layout factors allowing the analysis to provide independent results regarding process productivity and costs. Furthermore, it provides alternatives for the plant layout factor without considering the material handling factor. The modifications of the systematic layout planning procedure adopted in this research are described in section 2.4.1.2.

The other two approaches denoted, mathematical algorithms and software packages, does not referred to the contribution of the facility layout factors. Both of them produce a final version without the individual analysis of the facility layout factors. That is why these procedures are not included in this study. Further description of them can be found in Appendix 1.

To evaluate the individual impact of the facility layout factors is imperative to clarify the different measures for them. The next section introduces the facility layout factors and the quantitative and qualitative measures.

2.4 Facility layout design factors

Facility layout factors have become crucial to the design of a new facility or the improvement of an existent one. Several techniques to assess plant layout and material handling factors are introduced, highlighting the best alternatives.

The next section will focus on plant layout, taking into consideration the impact of it in the facility layout design. Further below, material handling factor is introduced. As well as with plant layout factor, relevant measures and impact of it to the overall process are highlighted.

2.4.1 Plant layout factor

As mentioned early, plant layout constitutes a crucial factor for facility layout design and an area where many improvements regarding productivity can be achieved. It involves the arrangement of different activities such as departments, machines, workstations, taking into consideration the sizes and shapes of them (Francis *et al.,* 1992). Moreover, flow of materials becomes an essential element of plant layout. As argue by Meyers and Stephens (2005) flow constitutes the heart of a plant layout and it is the path that every material or part takes in the plant during the manufacturing process. In addition, they suggest that there is a direct relationship between improving the product flow and the increase of profitability. Profit is defined as the net result between the incomes of a company and its expenses (Hofstrand, 2006).

For the reasons exposed, flow of materials becomes a crucial part of the plant layout improvements. Moreover, it is the starting points of the systematic layout procedure were the measure of the flow is established. Before addressing the quantitative and qualitative measure of flow, issues regarding backtracking and cross traffic are exposed.

The main objectives of a good flow design are to minimize the flow and the cost of it, and to maximize the directed flow paths. Meaning by directed flow paths, those that make progress from the origin to the destination without any backtracking (Tompkins *et al.*, 2003). In order to understand the statement form Tompkins *et al.* (2003), Meyers and Stephens (2005) states that backtracking occurs when the material is moved upstream in the process, meaning by these that it moves backward in the plant. The Figure 2.2 explains an example.

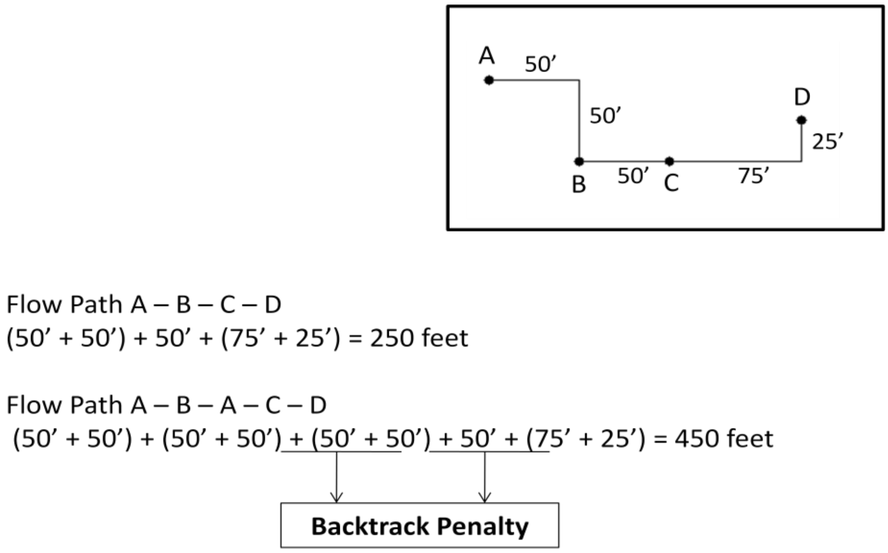


Figure 2.2. Illustration of how backtracking impacts the length of flow paths. *Source:* Tompkins *et al.* (2003).

The Figure 2.2 shows how backtracking influences on the length of flow paths, having an unnecessary distance travelled and making the flow inefficient. In this case, the penalty due to the backtracking is 200 feet; this extra distance will imply higher costs of transportation.

In addition to the elimination of backtracking, Meyers and Stephens (2005) also suggest the minimization cross traffic. They explain that cross traffic occurs when two or more flow lines cross each other. It is mainly problematic due to congestions and safety reasons. The Figure 2.3 shows the issue of cross traffic.

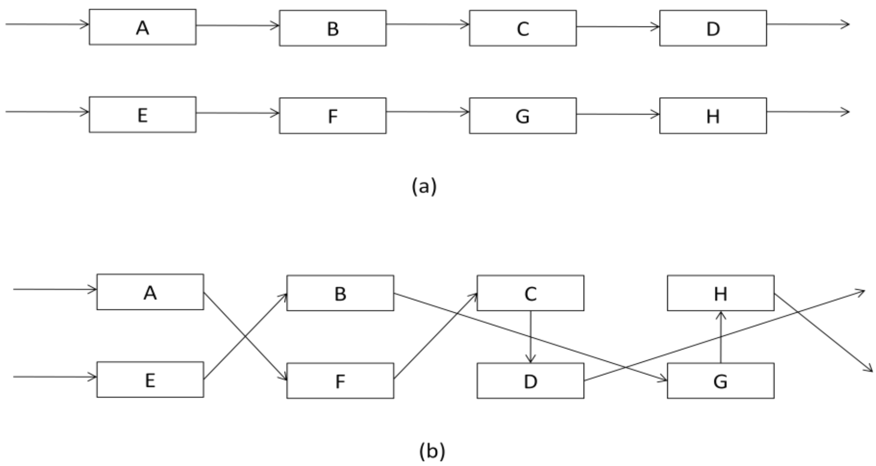


Figure 2.3. Impact of cross traffic. ***Source:*** **Tompkins** ***et al.*** **(2003).**

Image (b) in Figure 2.3 shows cross traffic between processes. Cross traffic has implications regarding safety and congestion in a facility layout design. The reduction of this problem as well as backtracking problems will improve the flow of materials and consequently the plant layout.

As describe by Tompkins *et al.* (2003) to established alternative arrangements of flow among departments it is imperative to define a measure of flow. The flow can be measured in a quantitative or qualitative manner. A company often will have a need for both types of measurement and both of them should be used to face the flow analysis problem (Tompkins *et al.*, 2003).

2.4.1.1 Quantitative measure of flow

There are many techniques to establish a quantitative measurement of flow. Meyers and Stephens (2005) propose techniques such as string diagram, multicolumn process chart and from-to chart. This techniques are explained below.

String diagram

The string diagram represents the flow of elements on a specific area of a layout (Apple, 1977). This technique is based on the distance travelled by the parts. The Figure 2.4 shows an example.

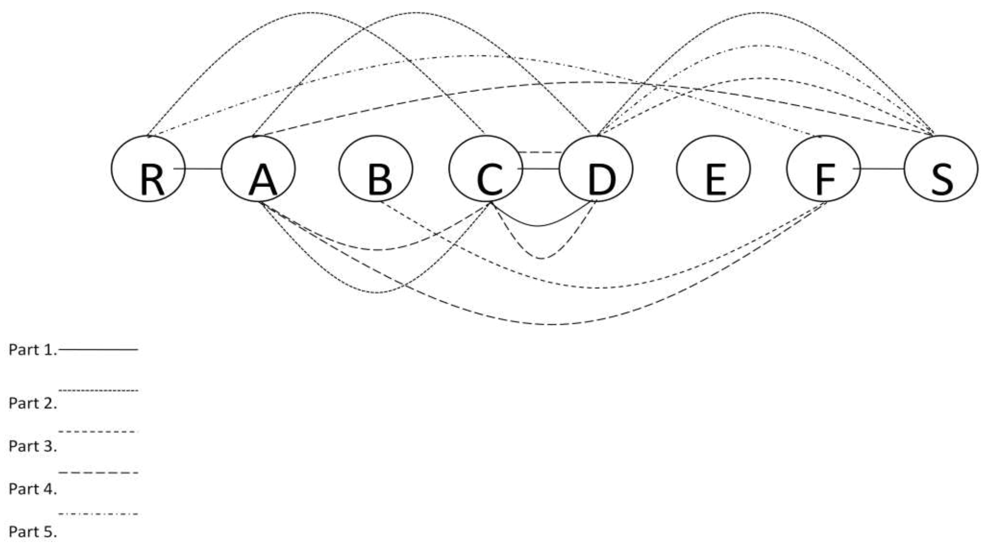


Figure 2.4. String diagram. *Source:* Meyers and Stephens (2005).

The circles represents the processes and the lines between them the flow of parts (Meyers and Stephens, 2005). Flow lines between adjacent processes are from and to the middle of circles. If any jumps between processes occur the line is drawn above the circles; lines below the circles correspond to backtracking (Meyers and Stephens, 2005). The objective is to calculate the total distance travelled and improve it with different alternatives.

The multicolumn process chart

The multicolumn process chart is another technique used to measure the flow. This chart seeks the same objective as the string diagram but utilizes a different diagram. An example is presented in Figure 2.5.

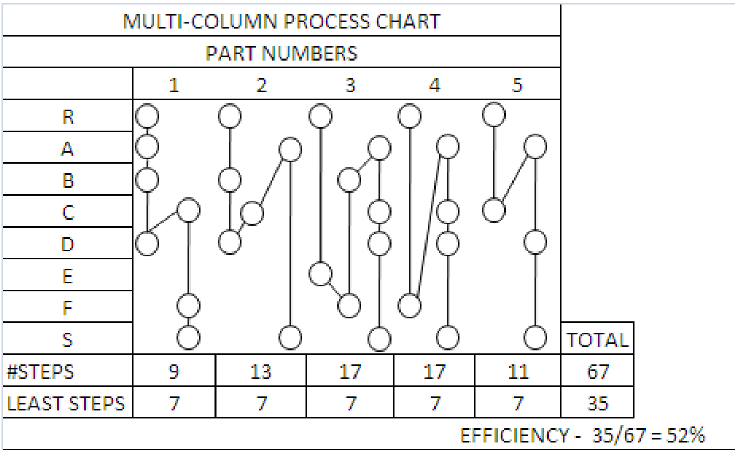


Figure 2.5. Multi-Column process chart. ***Source:*** **Meyers and Stephens (2005).**

In this technique, the improvements are visualized accordingly to the process chart drawn, trying to minimize, as in the string diagram, the total distance travelled by the different parts. Moreover, it provides an efficiency rate of the steps.

From-to chart

The other technique is the from-to chart that measures the amount of flow between departments. These measurements may include pieces per hour, pounds per week or moves per day (Tompkins *et al.*, 2003). It is a square matrix, but it is not symmetric. This is because there is no reason for the flow between departments to be the same. For example, the flow from stores to assembly could not be the same as the flow from assembly to stores (Tompkins *et al.,* 2003). The most important step in the construction of the from-to chart is to established a unit of measure of flow, in order to properly represent the relationships among the departments and volumes of flow (Tompkins *et al.*, 2003). This unit will be the same for entire flow so the materials will have to be arranged to be expressed in this unit. The Figure 2.6 shows an example of a from-to chart.

From \ To	Store	Milling	Turning	Press	Plate	Assembly	Warehouse
Stores		12	6	9	1	4	
Milling					7	2	
Turning		3			4		
Press					3	1	1
Plate		3	1			4	3
Assembly	1						7
Warehouse							

Figure 2.6. From-to chart. *Source:* Tompkins *et al.* (2003).

In the Figure 2.6 it is possible to appreciate that the matrix is not symmetric. As explained above, the lack of symmetry is because there is no reason for the amount of flow between processes to be the same.

Tompkins *et al.* (2003) argue that the most used technique of measurement is the from-to chart. This is supported by Meyers and Stephens (2005), arguing that from the three techniques presented the most accurate and exact one is the from-to chart.

Establishing the from-to chart helps to analyze and visualize the material movement because it expresses the movements in one unit of measure. Meaning by this that there will not be confusion on the quantities or different parts moving among the processes. In addition, the utilisation of the from-to chart will help to analyse the movement of materials and the planning of flow patterns (Apple, 1977). Flow pattern is discussed in the next section.

The clarity of this technique in addition to its accuracy are the two main reasons that supports the adoption of it in this research. Moreover, the volume movement between activities and the dependency among them will also be highlighted by the largest quantities expressed in the from-to chart. The from-to chart represents the quantitative measure of the flow for this research. The next section explains the qualitative measure.

2.4.1.2 Qualitative measure of flow

Qualitative measurement of flow has also a great impact on the flow structure. Francis *et al.* (1992) suggest that in order to assess the qualitative aspects of the flow an activity analysis must be elaborated and the most use technique is the activity relationship chart developed by Muther (1973). This is supported by Tompkins *et al.* (2003) that suggest the use of closeness relationships values, which are used in the activity relationship chart.

In addition Francis *et al.* (1992) argue that the development of the activity relationship chart is very valuable because it can take into account the aspects regarding the attitudes and preferences of the people involved. The activity relationship chart is similar to the from-to chart except that the numbers are replace by a qualitative closeness rating (Francis *et al.,* 1992). Closeness ratings or values will represent the desirability of having two departments close to each other or not, and the degree of this appreciation. Also it is important to highlight the difference between a closeness value of U and X. Two departments can be set to be adjacent if the closeness value is U; however they cannot be placed together if they have a closeness value of X due to safety issues, environmental and other facilities constraints (Tompkins *et al.*, 2003). The Figure 2.7 shows an example of an activity relationship chart.

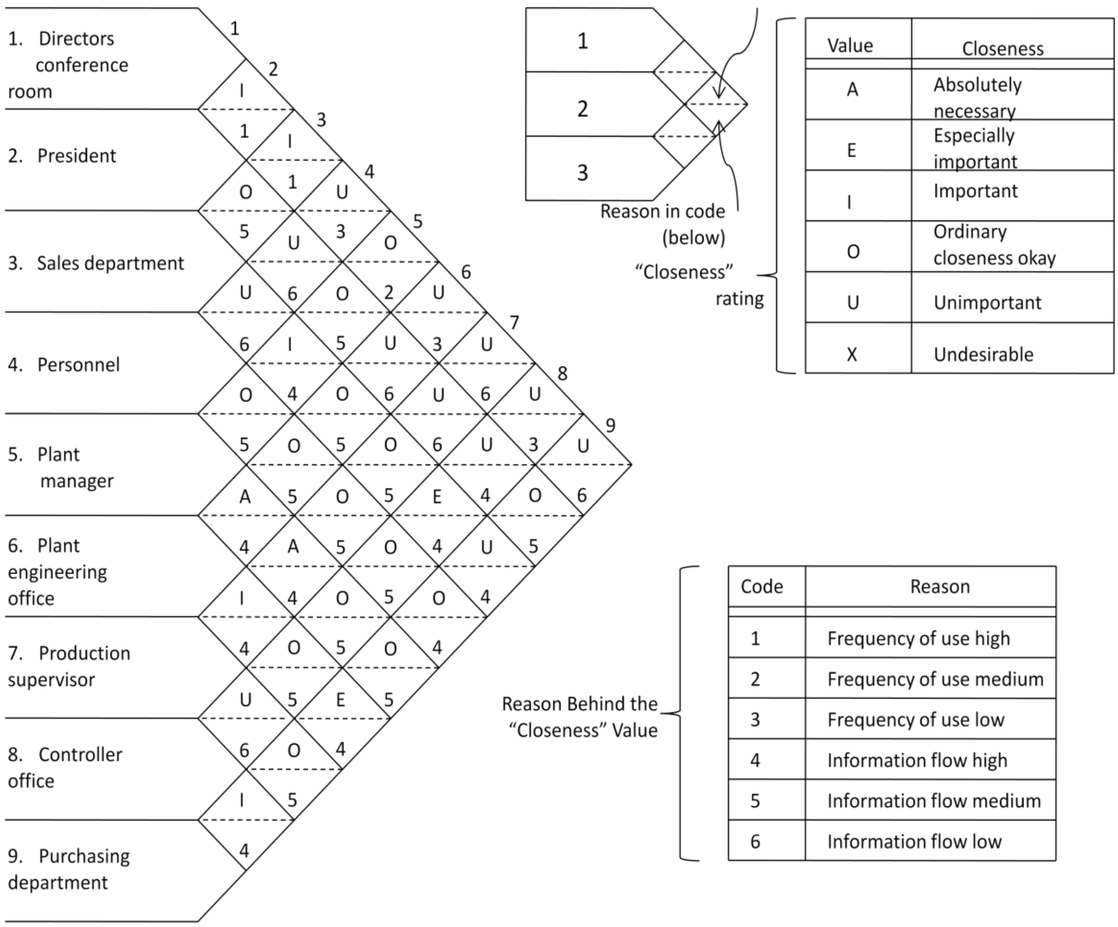


Figure 2.7. Relationship chart. *Source:* Tompkins *et al.* (2003).

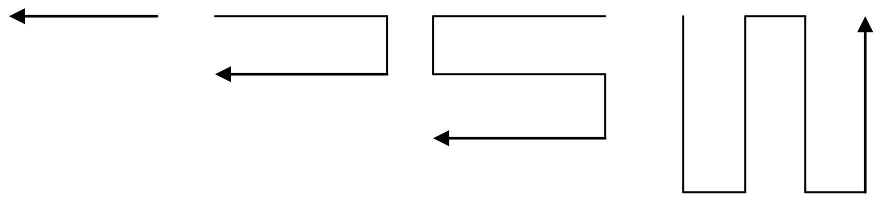
Besides from the closeness values shown in Figure 2.7 there is another table expressing "reason behind the closeness value". This table represent the reason why the layout designer chooses the closeness value. In this case of Figure 2.7, Tompkins *et al.* (2003) suggested those reasons for determining the closeness values. However, the reasons may vary depending on each activity relationship chart. For example, Francis *et al.* (1992) suggested the following reasons expressed in Table 2.1.

Table 2.1. Reason behind the closeness value. *Source:* Francis *et al.* (1992).

Code	REASON
1	Flow of material
2	Ease of supervision
3	Common personnel
4	Contact necessary
5	Convenience

Therefore the layout designer must evaluate in each case what reasons to apply in order to establish the closeness value among the different activities concerning the process.

Another important issue regarding plant layout analysis is the flow pattern. As argue by Tompkins *et al.* (2003) the flow pattern is a critical issue regarding the overall flow analysis. Apple (1977) as well as Tompkins *et al.* (2003) suggests main patterns to arrange the flow. These patterns are design according to the needs of the production process. For example, a straight line pattern is applicable when the production process is short; therefore the space required is not that significant. Other patterns are shown in the Figure 2.8.



(a) (b) (c) (d)

Figure 2.8. General flow patterns. (a) Straight-line. (b) U-shaped. (c) S-shaped. (d) W-shaped. ***Source:*** **Tompkins** ***et al.*** **(2003)**

For example, U-shaped pattern is useful when you required that the products finished at the same end of the process as they entered; S-shaped pattern is applicable where the production process is very long and the space is required to be use in an efficient way (Apple, 1977).

As mentioned above, this research includes qualitative and quantitative measurement of flow. These measurements constitute the starting points to develop the systematic layout procedure that will result in the alternatives for the plant layout factor. Regarding the steps of the procedure, the space relationship diagram is not utilised in the analysis. This is mainly because it implies a spatial representation of the processes as rectangular shapes. This is not accurate for the case study analysis. Therefore the utilisation of the software AutoCAD complements this step. This software is described in section 4.1.

2.4.2 Material handling factor

Many definitions have been established to material handling since the importance that have achieved in the facility layout design process over the years. Remembering the definition established by Tompkins *et al.* (2003) material handling "is the art and science of moving, storing, protecting, and controlling material". Also, they provide a more specific definition arguing that "material handling means providing the right amount of the right material, in the right condition, at the right place, in the right position, in the right sequence, and for the right cost, by the right method (s)".

Regarding the importance of material handling in a company, Apple (1977) argues that material handling can be responsible for the 50% to 75 % of the production activity, considerable higher than the usual 10% to 20 % quoted. Tompkins *et al.* (2003) support this relevance arguing that material handling effect on a manufactured product could be between 15% and 70% of the total cost of the product.

Having that influence on the manufacturing process, Apple (1977) suggests the following material handling objectives:

- Increased capacity.
- Improved working conditions.
- Improved customer service.
- Increased equipment and space utilisation.
- Reduced costs.

Tompkins *et al.* (2003) agree with the reduction of costs, the improvement of working conditions and safety and the improvement of customer service. In addition, they add objectives such as the improvement of material flow control, the reduction of inventories as well as the total manufacturing costs. Supporting what was said by Tompkins *et al.* (2003) and adding some objectives Sule (2009) suggests the increase of productivity and the facilitation of the manufacturing process.

In order to accomplish these objectives, an essential part of material handling is the unit load. As described by Tompkins *et al.* (2003) is “one of the most important elements of a material handling system”. Apple (1977) defines the unit load concept as “a number of items, or bulk material, so arranged or restrained that the mass can be picked up and moved as a single object, too large for manual handling, and upon being released will retain its initial arrangement for subsequent movement. It is implied that any single object too large for manual handling is a unit load”. Tompkins *et al.* (2003) argue that “is the move that defines the unit load”. Therefore, any item or items in a full or half full container that are moved in one single move will be considered as a unit load (Tompkins *et al.*, 2003).

The size of the unit load will have a great influence in the development of the material handling factor. By selecting the appropriate unit load size it is possible to minimize the material movement, standardized the equipment for moving and storage of materials, increase the utilization of the equipment and improve the protection and security of the product (Rushton *et al.*, 2001). The Table 2.2 is elaborated from Tompkins *et al.* (2003) implications on unit load size decision.

Table 2.2. Unit load size.

Small Unit Load Size	Large Unit Load Size
• Often require simple material handling methods. • Increase in transportation requirements. • Reduced work-in progress inventory. • Material handling time increases.	• Require bigger and heavier equipments and wider aisles. • Fewer moves. • Increase work-in progress inventory.

The decision regarding the unit load size will depend on the manufacturing process and the material handling equipment available at the facility. Two elements must be taken into consideration: the “cube” limit and the weight limit (Tompkins *et al.*, 2003). The “cube” limit refers to the volume that the unit load can handle and the weight limit to the maximum weight it can support.

Besides the unit load, material handling factor is measured in this research with two ratios proposed by Lamprecht (1982) and then supported by Sule (2009). The first ratio is the material handling labour ratio. This ratio provides the opportunity to analyze the “percentage of labour dollars that are being expended to carry out material handling duties” (Lamprecht, 1982). The ratio is presented below.

$$Material\ Handling\ Labour\ Ratio = \frac{Personnel\ Assigned\ to\ Material\ Handling\ Duties}{Total\ Plant\ Operating\ Personnel}$$

Sule (2009) suggests that the ratio should be less than 1 and a proper value should be 0.30 or inferior. The other ratio analyses the space utilisation. The formula is shown below:

$$Storage\ Space\ Utilisation = \frac{Storage\ Space\ Occupied}{Total\ Available\ Storage\ Space}$$

This ratio presents how efficiently the storage space has been used and it is very important due to the increasing costs of storage (Lamprecht, 1983). Sule (2009) suggests a value near 1 to stated that the storage space have been used efficiently.

Beside the definition of the two facility layout factors and the elements they involved, the relationship between them must be established. This relationship is discussed in the next section.

2.5 Facility layout factors relationship

Plant layout factor mainly defines the arrangement of the processes and the flow of materials of a facility layout design. On the contrary, material handling factor defines the unit load to utilise, the equipment and personnel necessary for the movement of any kind of materials. Taking into consideration just the definition the only thing they have in common is that plant layout defines the flow of materials and material handling deals with the materials around the facility. However, both factors are much related when it comes to the evaluation of them proposed in section 2.6, especially in terms of costs.

Cost evaluation of plant layout factor considers the distances, cost of transportation and amount of flow between the processes. Material handling cost evaluation considers the same inputs as for plant layout factor. However the difference is that in plant layout factor the variable input are the distances that change in respond to changes in the arrangements of the processes. The cost of transportation remains the same because it is part of the material handling factor as part of the equipment for those moves. Thereby, in the case of material handling factor the variable input is the cost of transportation and the distances remain constant. In both cases the amount of flow is invariable because the production is maintained constant.

This difference in the evaluation is done to provide an individual result for both of the facility layout factors. Having this individual result helps to clarify the individual impact of the facility layout factors and their contribution to the overall impact of facility layout design. The next section explains the evaluation method.

2.6 Facility layout factors evaluation

The facility layout factors are evaluated to measure the impact they have on the productivity and costs. Although the two factors are measured and analysed separately, the impact on productivity is measured in the same way. As mentioned in section 2.1 productivity is the ratio of outputs (goods and services) divided by the inputs (resources, such as labour and capital) (Heizer and Render, 2008). There are two main productivity measurements: single-factor and multi-factor. The difference among them is that single-factor as the name says includes only one factor as an input. On the other hand, multi-factor includes two or more inputs (Slack *et al.,* 2004).

In order to compare the impact on productivity of both plant layout and material handling a multi-factor approach is used. Even though there are multiples unit of measure for productivity such as m^3 per man hour or m^3 per unit of time the selection of m^3 per US$ is used because it makes possible the comparison between the inputs (labour and capital) in the same unit. For example, if the plant layout factor influences on the labour input and the material handling factor affects the capital input both measures could be easily compare due to the utilisation of the same unit of measure. The formula that is used is presented below.

$$Productivity = \frac{Outputs}{Inputs} = \frac{Production}{Labour + Capital}$$

The production and the input resources are measured monthly. The production is obtained from the company's records as well as the cost of the labour and the necessary capital to produce. Labour resource includes the salary of the workers involved in the process and capital resource includes all the necessary raw materials, machines, equipment and others involved in the process. These results will be compared against the proposed alternatives in order to reveal the facility layout factor with the greatest impact on productivity.

The following two sections explain the evaluation method to analyse the impact on cost reduction due to changes in the facility layout factors. The results of the productivity and the costs analysis are compared in chapter 4.

2.6.1 Plant layout factor evaluation

To establish a relationship between the plant layout and the improvements that can result due to alternatives in its configuration a measure must be established to evaluate quantitatively these improvements. This measure will be based on the distance and cost that materials incur along the process. The equation to be used is presented by Meller and Gau (1996) and Tompkins *et al.* (2003) among others.

$$\min z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} c_{ij} d_{ij}$$

Where "*m* denote the number of departments, f_{ij} denote the flow from department *i* to department *j* (expressed in number of unit loads moved per unit time), and c_{ij} denote the cost of moving a unit load one distance unit from department *i* to department *j*" (Tompkins *et al.*, 2003). The last variable is d_{ij} that it is the distance from department *i* to department *j*.

Regarding the distance Meller and Gau (1996) suggest two measurements: distances between input/output points and centroids-to centroids. Distance measure from input/output points of the departments may also include the distance travelled along the aisles in between these points (Meller and Gau, 1996). They also suggest that this type of measure is useful when the layout is known. The second method of measurement is from centroids to centroids. They argue that this type of measure is useful in cases where the layout has not been developed and the input/output points are unknown. Regarding the analysis of the case study the first measure will be used because of the existent layout and the higher accuracy it represents.

This equation will serve as the evaluation for the current facility layout design and the alternatives generated of plant layout factor. Even though the equation evaluates the costs, the different aspects discussed such as flow pattern, activity relationship and practical limitations are included in the rearrangement of the process due to their importance. Consequently the distances among processes are also affected by these qualitative aspects. Therefore, the costs also reflect these issues.

2.6.2 Material handling factor evaluation

As well as with plant layout factor, material handling is evaluated by the costs incurred by the materials in the layout design. However, as mentioned in section 2.5, the material handling factor is evaluated on the current layout design. This means that the configuration of the processes and the distances among them remains constant. The cost of transportation may vary according to the unit load decided that defines the equipment of transportation. In addition, other equipments related to material handling are analysed.

Besides the unit load and the material handling equipment, material handling factor is evaluated with the ratios introduced in section 2.4.2. These ratios provide reasonable comparison between the alternatives of the material handling factor.

2.7 Research question emergence

The literature regarding facilities layout design is extensive and some particular issues were addressed in this chapter. The first issue concerns the implications of facility layout design. Frazelle (1986) argues that a significant cost saving can be achieved by reducing the material handling activities. Tompkins *et al.* (2003) took a step forward in this discussion arguing that by having a better facility design the percentage of cost reduction could be increased at least to a range of 10% to 30%.

A second issue discussed that emerges from the different point of views are the objectives of facility layout design. For example, Francis *et al.* (1992) agreed on several objectives highlighted by Apple (1977) but did not agreed on the objective regarding the maintenance of high turnover of work-in process and the facilitation of the manufacturing process. Tompkins *et al.* (2003) proposed different objectives such as the effective utilisation of resources referring to equipment, people, space and others.

As well as with facility layout design, the scope of the facility layout factors is not clear. Authors suggest different quantifications in terms of costs mainly for material handling factor. However, improvements regarding productivity are not established. For plant layout factor, the situation is the same. The lack of quantification of these factors that interferes with the clearness of the impact of facility layout design encourages the emergence of the research question. Moreover, the research question compares this two facility layout factors in order to establish the impact of them on process productivity and costs and therefore clarify the overall contribution of facility layout design.

2.8 Summary

This chapter has provided an in-depth discussion of the literature of facility layout design. The different point of views regarding the definition, factors and objectives are highlighted. Moreover, the existent approaches to face facility layout design are introduced. In addition, the two facility layout factors, plant layout and material handling, are established with the corresponding qualitative and quantitative measure of them.

With the two facility layout factors defined, the evaluation of the impact of them on process productivity and costs is explained. This will help to measure the impact in the case study analysed in chapter 4. Finally the research question emergence is highlighted. This research question will focus on the individual impact of the facility layout factors towards achieving process productivity and costs reduction.

CHAPTER 3: Research Methodology

3.1 Introduction

The research examines the impact of facility layout design in the process productivity and costs. In order to do so, relevant literature review was done considering the objectives of facility layout design and the individual factors involved in the process of generation or improvement of the facility layout. Furthermore, a real case study is explored and analyzed.

According to Yin (2009) a case study is defined as an empirical research that tries to understand in depth a particular phenomenon studying it in its real-life context. In addition he suggests that case study method “allows investigators to retain the holistic and meaningful characteristics of real-life events such as individual life cycles, small group behaviour, organisational and managerial processes”.

In addition to this definition, Stoecker (1991) argued that a case study is a complete method that covers several aspects such as the logic of design, data collection techniques and approaches to analyse the relevant data. Furthermore he suggests that the case study is not limited to a data collection exercise or a design feature, it comprise both activities. Yin (2009) highlights that the case study is ideal to examine contemporary events especially when the important behaviours regarding the phenomenon cannot be manipulated or modified. This is highly accurately to the case study that will be presented because even though alternatives to the facility layout will be proposed with some improvements if it is possible; the modification of the relevant behaviours by the researcher will be theoretically and, if it is the case, real modifications could be conducted by the company.

An issue regarding single case studies is the possibility to apply the research findings and the generalization of them. Yin (2009) argued that a single case study can be generalized to “theoretical propositions and not to populations or universes”. Meaning by this that the results of a single case study may not be applicable to a similar case study and may result that it is not applicable to any other case study. Finally he suggests that the goal of case studies is to generalize theories rather than enumerate the applicability in other cases of research.

3.2 Data required

As mentioned early, the research study will be focus on a company case: Urupanel. The study will measure certain characteristics of the company's facility layout design in order to evaluate and suggest, if it is possible, some recommendations. The Table 3.1 shows the necessary information that must be gathered.

Table 3.1. Facility layout factor and data required.

Facility Layout Factor	Data Required
Plant Layout	• From-to chart • Activity relationships • Distances between processes • Cost of transport (of the unit load) between processes • Cost of relocation of processes • Flow pattern • Practical limitations
Material Handling	• Unit loads utilisation • Personnel assigned to material handling duties • Total plant operating personnel • Storage space occupied • Total available storage space • Material handling equipment use in the transportations • Practical limitations

As argued by Eisenhardt (1989) case studies usually involve several data collection methods such as interviews, archives and questionnaires that gather qualitative and quantitative evidence. This is supported by Yin (2009) arguing that some case studies use more than one type of research and use a mix of qualitative and quantitative evidence. Furthermore he suggests that a unique strength of case study methodology is the ability to handle a wide variety of sources like documents, archival records, interviews and observations.

The diversity of sources argued by Yin (2009) and Eisenhardt (1989) is adopted in this study. Interviews, company records and observations are utilised. Furthermore, the nature of data required that involves facts and opinions encourages the use of both qualitative and quantitative research methodologies. As argued by Bryman (1988) the combination of these two types of methodology it is justified by the capitalisation of the strengths of them and the compensations of their weaknesses and also by the consideration of the practical issues involved in the research. These two research methods and the different sources of evidence are discussed in the next two sections.

3.3 Qualitative research

As defined by van Maanen (1983) quality research includes an "array of interpretive techniques which seek to describe, decode, translate, and otherwise come to terms with the meaning, not the frequency of certain more or less naturally occurring phenomena in the social world". This is supported by Cooper (2008) that states that qualitative research refers to the definition or meaning that characterize something.

As mentioned in the previou section, there are many sources of evidence. Some of them can be gathered using a qualitative research methodology. The sources relevant to this methodology and their strengths and weaknesses are listed below in Table 3.2.

Table 3.2. Sources of evidence. ***Source*** **(modified): Yin (2009).**

Source of Evidence	Strengths	Weaknesses
Documentation	• Stable (can be reviewed repeatedly) • Unobtrusive (not created as a result of the case study) • Exact (contains exact names, references, and details of an event) • Broad coverage (long span of time, many events, and many settings)	• Retrievability (can be difficult to find) • Biased selectivity, if collection is incomplete • Access (may be deliberately withheld)
Interviews	• Targeted (focuses directly on case study topics) • Insightful (provides perceived causal inferences and explanations)	• Bias (due to poorly articulated questions) • Response bias • Reflexivity (interviewee gives what interviewer wants to hear)
Direct observations	• Reality (covers events in real time) • Contextual (covers context of "case")	• Time consuming • Selectivity (broad coverage difficult without a team of observers) • Reflexivity (event may proceed differently because it is being observed) • Cost (hours needed by human observers)

The study incorporates these three sources of evidence as part of the data collection of the case study. The first source of evidence, documentation, can be documents such as proposals and progress reports; formal studies or evaluation of the company; letters an even e-mail correspondence (Yin, 2009).

Interviews are one of the most important techniques available for data collection in qualitative research (Cooper, 2008). This is supported by Yin (2009) arguing that interviews are a primary source for case study information gathering. He suggests that interviews should not only satisfy the inquiries of the interviewer but also try to ask friendly and nonthreatening questions to the interviewee in order to have a proper response from them. The utilisation of interviews in this study is supported mainly because of the need to have different opinions regarding the topic of facility layout design and also because of the nature of the data needed explained early. There are different types of interviews that will be discussed in section 3.5.

The last source of evidence described in the table is 'direct observations'. As argue by Yin (2009) this type of source can have to different types of data collection: formal and casual. In formal types the use of observational instruments is mainly used. An example of formal observation would be established charts to register the events. An informal observation would be a simple inspection of the events by the researcher. Direct observations methods will be discussed in section 3.4.

3.4 Quantitative research

Remembering the definition established by McEwan (2000) "qualitative refers to the meaning, the definition or analogy or model or metaphor characterising something, while quantitative assumes the meaning and refers to a measure of it". As described by Cooper (2008), quantitative methodology tries to answer questions regarding how much, how often, how many, when and who in the event. He also suggests that in this type of research the person in charge of it should maintain a distance from the events in order to avoid the effect of him or her in the results.

As well as in qualitative research, there are sources of evidence to gather quantitative information. The main two ones are: archival records and direct observations. Regarding archival records the strengths and weaknesses are the same as those from documentation presented in table 3.2. However, archival records are more precise and usually quantitative and also may have access difficulties due to privacy reasons (Yin, 2009). Cooper (2008) highlights that for some studies archival records may be very important, becoming the main source of quantitative analysis. However, he suggests that the researcher must be aware of the conditions under which this records were produced and their accuracy, explaining that "numbers alone should not automatically be considered a sign of accuracy". Examples of archival records are maps and charts. As referred in the previous section, direct observation may include formal and casual observation.

3.5 Data collection

As discussed in the previous sections, data collection will include qualitative and quantitative methodology. The sources of evidence that will be used to gather the relevant data from the case study are: documents, archival records, direct observations and interviews. Documents and archival records, as explained in sections 3.2 and 3.3, will consist in administrative documents such as proposals and progress reports, production charts, monthly production reviews and other documents useful for the research. These sources will be used to gather information regarding the flow of materials between processes and cost of unit loads transportations if it is available in these sources. Also information regarding personnel and layout designs will be collected through these sources.

Direct observations will vary from simple inspections that are recorded in notes to proper utilisation of charts. Mainly direct observation techniques are used to assess the material handling factor.

The last source of evidence is the interviews. This technique will try to fill any gap or uncovered information of the previous techniques. Also, it will provide the company's perspective regarding different aspects of their layout and may also add some aspects that were not include in the previous stages. There are many types of interviews and can be classified according to the structure that follows and the number of participants. Cooper (2008) argues that there are three types of structures: unstructured, semi-structured and structured. The Table 3.3 shows the description by Cooper.

Table 3.3. Interview types.

Interview	Description
Unstructured	"no specific order of topics to be discussed, with each interview customized to each participant; generally starts with a participant narrative"
Semi-structured	"generally starts with a few specific questions and then follows the individual's tangents of thought with interviewer probes"
Structured	"often uses a detailed interview guide similar to a questionnaire to guide the question order and the specific way the questions are asked, but the questions generally remain open-ended"

As discussed by Cooper (2008) a structured interview is more rigid, meaning that the responses will just focus on the question ask being these the major weakness. However he also suggests that the main strength of this interview is the possibility to compare different answers because of the small variability of these answers.

On the contrary, unstructured and semi-structured interviews will allow the participant to provide in some cases relevant information that was not asked for, due to the conversation that it is established between the interviewer and the participant. Yet, this type of interview will require a much more skilled and creative interviewer to take advantage of this type of interview (Cooper, 2008).

The other classification regards the number of participants. Cooper (2008) describes two types: individual depth interviews and group interviews. The main difference is that, as the name says, an individual interview consists in only one participant and group interviews are developed to more than one participant. Also Yin (2009) suggests that with in-depth interviews the participant may propose topics or other participants to be interviewed. Due to the company regulations and recommendations, group interviews will not be conducted.

Regarding the case study, the interview type chosen is a semi-structured interview. The reason is mainly because there are a number of questions that must be asked and also the advantage of having the opinion of the company workers could bring out different relevant aspects that were not taken into consideration. In addition, the possibility of comparison between the different interviewees due to the questions established will allow the detection of critical aspects.

The questions involved in the interview are detailed in Appendix 2. There will be only one set of questions, even though some workers could have less relevant information than others, yet the questions will be asked anyway, due to the possibility that other aspects could arise.

The selection of workers for the interviews will be based on the position they have in the company and the influence on the facility layout factors. The Table 3.4 shows information about the participants' position in the company, the date and an estimated interview length.

Table 3.4. Interview information.

Company position	Interview duration	Date	Length (approximately)
Mr. Jose L. Saenz	Board Member	07-18-2009	1 hour 20 min
Mr. Rodrigo Correa	General Manager	07-18-2009	50 min
Mr. Fabrizio Blengio	Plant engineer	07-20-2009	1 hour

A second meeting was held on the 09-11-2009 with Mr. Jose L. Saenz and Mr. Rodrigo Correa for further details on the capital resources needed for the production and other remaining issues. The selection of these three persons was mainly based on the influence they had in the development of the existent layout. They actively interfered in the decisions regarding the arrangement of the processes as well as the material handling issues. Also they can provide a comprehensive point of view regarding the processes because they know how all the processes work and the interaction between them.

The questions included in the interview will try to answer main issues involved in the research question presented. Also, the questions will highlight the company's position regarding the facility layout design, the facility layout factors and their opinion towards the influence of them in productivity and costs. The interview questions are in Appendix 2, yet the aims of the questions are explained below.

Question 1 aims to introduce the subject to the interviewee and to reveal his opinion towards the main processes involved in the manufacturing of plywood. The next question tries to understand if the interviewee is aware of the scope of facilities layout design and the benefits it can bring to the company. Furthermore the impact in productivity and costs reduction is approached. Question 3 focuses on the backtracking problems and tries to reveal if the interviewee is aware of the existent problems and the impact they have. Questions number 4, 5 and 6 refers to the flow and specifically to its pattern and the relationship between the different processes.

Questions 7, 8 and 9 focus on the material handling factor. The interviewee is ask about the relevance of the personnel and the equipment, the unit load that is used and the possible waste of personnel due to material handling activities. Questions 10 and 11 aimed to clarify the reasons behind the location of work-in process areas and storage. Question 12 deals with the dust produce in the manufacturing process and the limitation it could involve in other location of processes. The last question aims to know the opinion of the interviewee regarding the rearrangement of the different processes and the feasibility of these changes.

3.6 Summary

In this chapter several aspects were highlighted. First, the relevant aspects regarding the selection of a single case study were presented. These refer to the issues of generalisation of a single case study and the use of multiple sources of evidence. These sources of evidence can be documents, archival records, interviews and direct observations. Each of them has its own strengths and weaknesses presented in table 3.2. Another aspect mentioned is the data required for this study. This data is mainly to define the characteristics of the facility layout factors: plant layout and material handling.

Finally, the main types and characteristics of the sources of evidence were introduced. In this aspect, a main issue was the selection of the interview type. In this research, the interview selected was a semi-structured interview, due to the necessity to ask a set of question and the possibility to establish a conversation with the participant that can bring out more relevant aspects regarding the case study.

CHAPTER 4: Case Study Urupanel

4.1 Introduction

In this chapter the case study is analysed. Previously to the analysis the plywood manufacturing process is explained to have a global point of view of the process. Then the plant layout factor analysis is addressed introducing the current state of the facility layout design and the problems it has. After this section the different alternatives for the plant layout factor are explained and the impact they have on productivity and cost reduction. The same procedure is repeated for the material handling factor analysis. Having these two analyses will help to compare and clarify the answer for the research question proposed.

The different alternatives that are proposed especially for the flow analysis are developed on the software AutoCAD. This software uses computer aided design (CAD) to create 2D and 3D designs. The use of this software is based on the fact that the case study company used it to develop the existent layout and make modifications to it. Furthermore, it simplifies the generation of alternatives due to the existent documents in this format. This software replaces the space relationship diagram of the systematic layout procedure.

4.2 Plywood manufacturing process

Plywood manufacturing process consists mainly in eleven processes. As shown in Figure 4.1 the materials follow a simple route among processes and the only deviation of this route occurs after the work-in process area 2 (WIP2) and the dimensional cutting process.

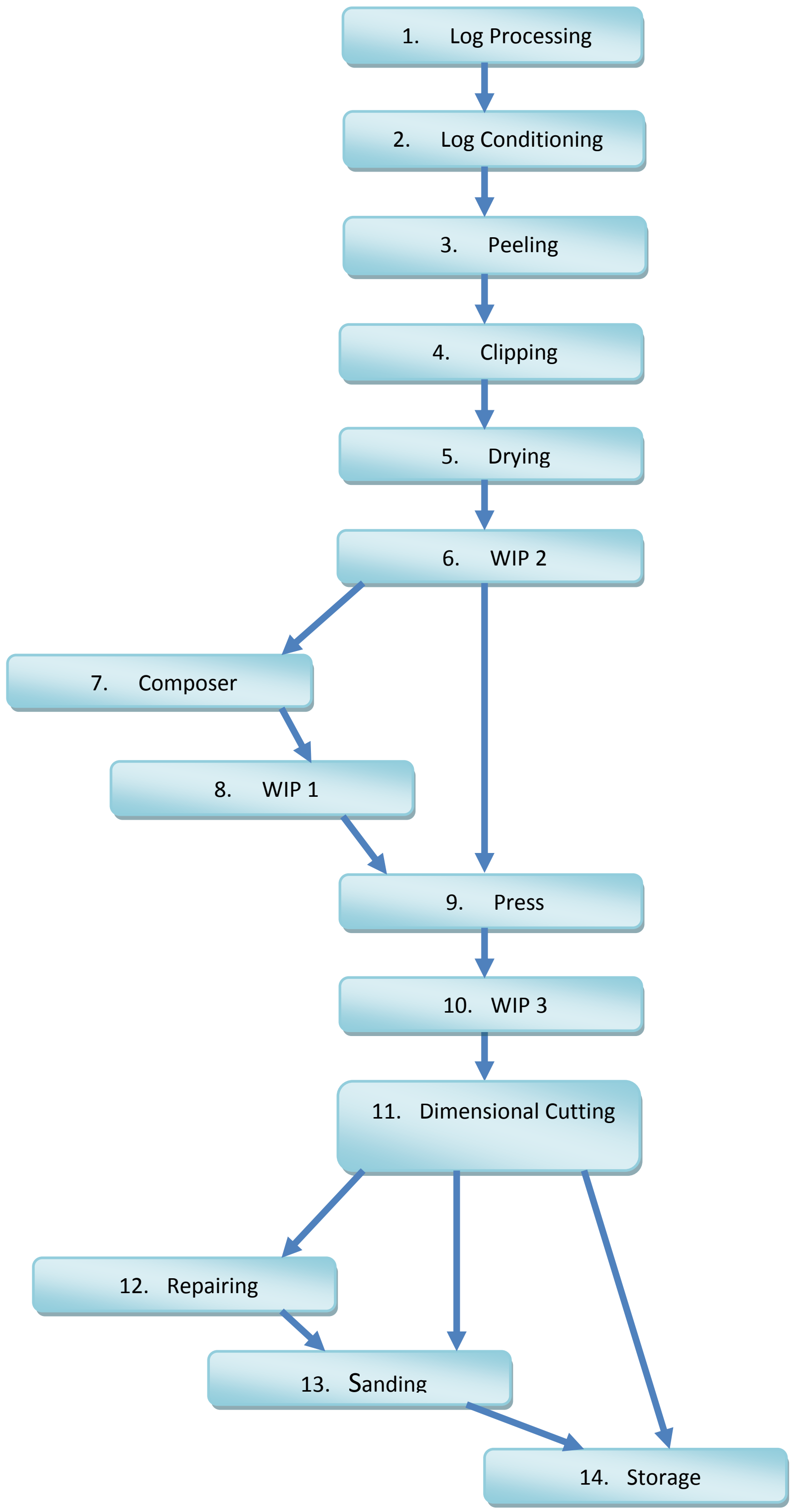


Figure 4.1. Plywood manufacturing process.

Below is a detailed explanation of the different processes involved in the manufacturing of plywood.

Log Processing: in this process the unprocessed log is removed from its bark so that the log is ready for the conditioning process. The machine uses special knifes to remove the bark and, if necessary, the logs are cut with a saw to a specific length for the conditioning process. The logs are transported by a front loader to the next process.

Log Conditioning: the debarked logs are introduced into macerate tunnels in order to obtain softness and plasticity by the method of water saturation. This is done by showering the logs with hot water (80°C) and a solution of caustic soda at 0,085% to obtain the needed pH (7,5 to 8) for a time not less than 16 hours. After the conditioning the logs are transported by a front loader to the peeling process.

Peeling: in this process the conditioned logs which have an average inside temperature of 40 °C are peeled. In the initial peeling the lathe produces waste because the initial layers of the log are not uniform. This waste is used to feed the boiler that provides the heat for the drying and pressing process. When the layers of the log become uniform they are send to the clipping process by a conveyor belt. There is another sub product in this process that is the core of the peeled log. This is processed into chips that also feed the boiler.

Clipping: in this process the uniform layers or veneers of the log are cut to eliminate the defects that they have. This generates the needed veneers according to specifications and pieces of veneers called "randoms". The veneers are automatically stacked. Then the stacks are driven to the drying process by a crane fork.

Drying: currently there are two dryers in the company. The veneers goes through a moving tunnel were it loses its humidity by the application of hot circulating air (180 to 200°C). Then the veneers are stacked manually in custom trolleys to make the loading of the crane fork easier. Afterwards the stacks are driven to a work-in process storage were the veneers are storage for no less than 48 hours to stabilize their temperature and humidity. This storage area is referred as work-in process 2 (WIP 2). After the resting the randoms are transported to the composer and the veneers to the gluing and assembly process. These two routes are travelled with a crane fork.

Composer: in this process the randoms are cut by knifes to eliminate their defects. Then the pieces are glued obtaining the "short veneers". These veneers are the ones that go inside the plywood with their fibres in a perpendicular direction. After a stack is filled a crane fork moves them to the gluing and assembly process.

Gluing and Assembly: this process receives the short veneers from the composer and the veneers from the work-in process storage. Then the plywood is assembled by the corresponding veneers. Each layer goes through a gluer were the gluing substance is applied. At the exit of the gluer, two workers assembly the plywood by putting a whole veneer at the bottom, then a short veneer, then a whole veneer and so on until the required thickness is achieved. Then the assembled plywood is moved to the pressing process by a conveyor belt.

Press: the glued veneers enter a cold pre-press where pressure is applied to consolidate them. Afterwards the workers move the plywood into the loader of the hot press. Pressure is applied to the plywood to finish the gluing between the veneers. At the exit of the press the plywood is sprayed with cold water to reduce the tensions and the warping of the plywood. Then the plywood is moved by a crane fork to the work-in process area (WIP 3) to a cooling period of approximately 12 hours. After this period the plywood is move to the dimensional cutting or trimming process.

Dimensional Cutting: in this process the plywood is cut according to the width and length specifications. The remaining pieces are used as raw material for the boiler. As shown in Figure 4.1 after this process are three possible routes: repairing, sanding and storage. The plywood with some defects is send to the repairing process. Others are moved to the sanding process and others to the storage as finished products. The routes will depend on the quality of plywood that is being manufactured.

Repairing: in this process the defects of the plywood are removed in the first layer of the plywood without reaching the gluing section. Then the defect is repaired by using a synthetic substance based on polyurethane. The repaired plywood is moved to the sanding process by a crane fork.

Sanding: in this process the plywood from the dimensional cutting and repairing process are sanded. After this process the finished plywood is moved to the storage of finished products.

The cut pieces of veneers from the composer, repairing and unusable veneers from the drying process are moved by an underground conveyor belt towards a raw materials storage area for the boiler. The packaging process is not included because is done at the entrance of the storage of finished products and it is done manually.

4.3 Plant layout factor analysis

4.3.1 Current state

The current layout was design previously to the installation of the plant. However, during the years of functioning of the plant the layout has been modified to fulfil new restrictions. For example, a new press was added to the process and an automatic stacker for the clipping machine was installed. These modifications have altered what was supposed to be an ideal layout design. Figure 4.2 shows the existent layout.

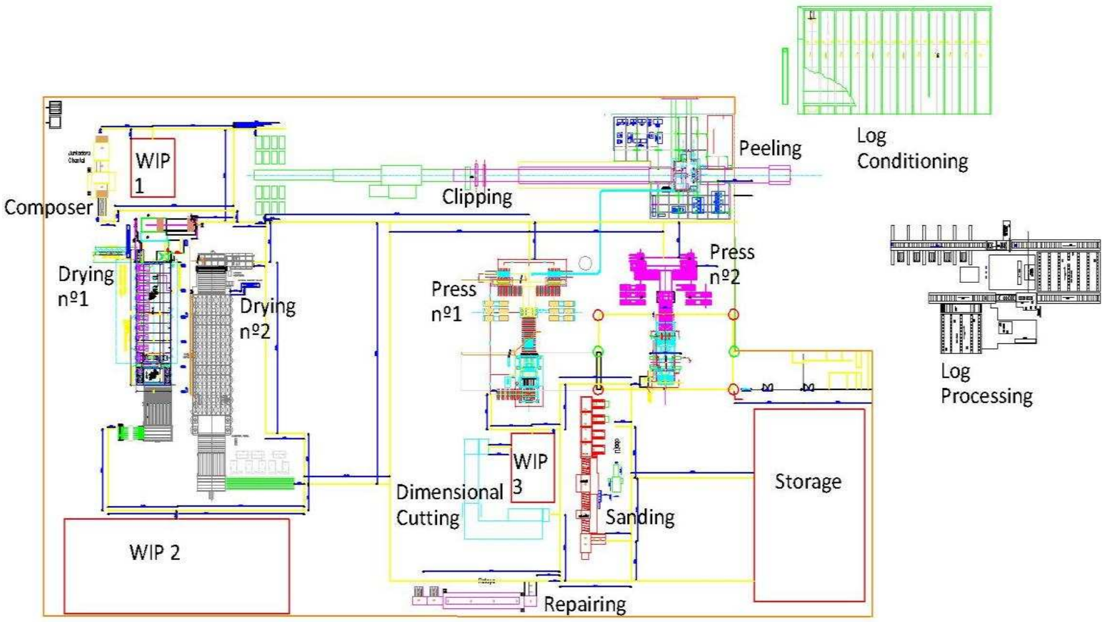


Figure 4.2. Current Layout. ***Source*** **(modified)*:* Urupanel.**

The existent layout shows a dominant s-shaped pattern. This is mainly justified because the space must be effectively utilised to configure the different machines and handle the work-in process. Even though the pattern is well adopted, there are some backtracking issues that can influence negatively in the layout by increasing the length and the possibility of cross traffic between processes. The Figure 4.3 shows the s-shaped pattern used in the current layout highlighted in red.

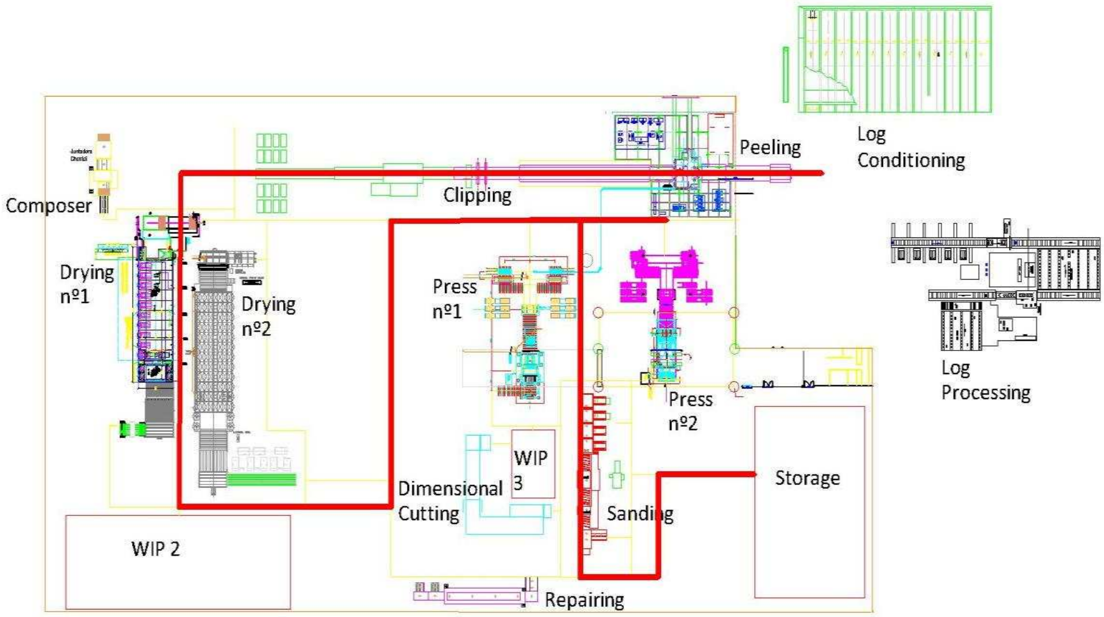


Figure 4.3. S-shape pattern. *Source* (modified): Urupanel.

There are two main reasons why this pattern fits accurately the plywood manufacturing process. First, the process has mainly one route until the cutting and trimming so the available space can be used in the most effective way without concerning about cross traffic between processes. The second reason is that if the processes would not be arranged in an s-shaped pattern the entire manufacturing process would be too long and the space would not be effectively utilised.

As mentioned the current layout has backtracking problems. These problems add unnecessary distance travelled to the materials and therefore increases the cost of transportation. These problems are discussed below.

Backtracking

In terms of backtracking the current layout presents two problems. The first issue arises between the work-in process area 2 and the composer process. The cut veneers that were dried and need to be compose must travel backwards in the process towards the composer machine that is located above dryer nº1. Figure 4.4 shows this backtracked movement highlighted in blue.

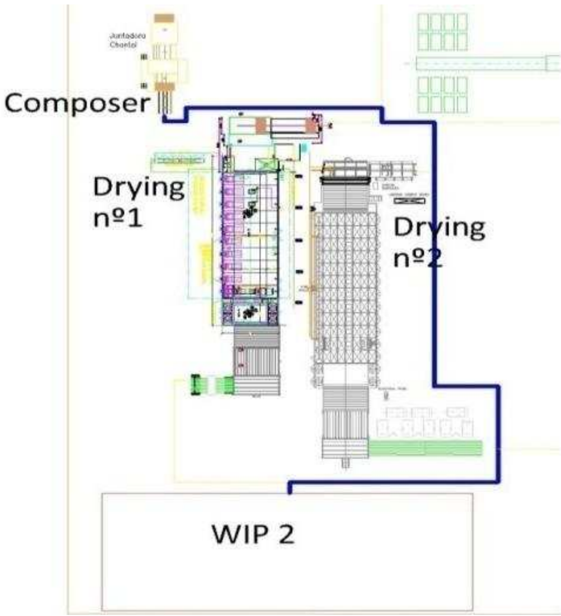


Figure 4.4. Backtracking problem 1. *Source* (modified): Urupanel.

This distance travelled backwards increases the total path length that the materials must follow. This extra distance is revealed further in Table 4.1 when the total distance of the process is calculated. The second backtracking problem occurs after the veneers are press down in press nº2. The veneers then must travel backwards to the dimensional cutting process. Figure 4.5 shows this movement.

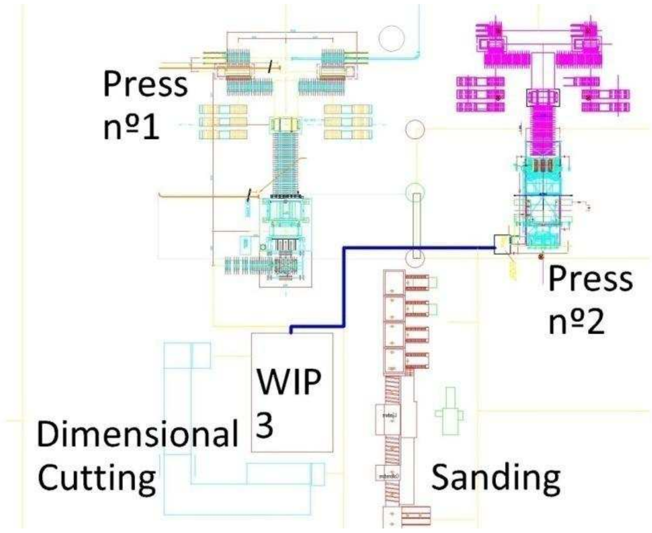


Figure 4.5. Backtracking problem 2. *Source* (modified): Urupanel.

As well as with the previous backtracking problem these extra distances are explained in subsection of evaluation of current layout were the analysis of the different distances among processes and the cost of transportation is addressed.

Cost evaluation

As mentioned early the calculation of the total distance that materials incur along the process is a key method to understand possible ways to improve the arrangement of processes and consequently the flow. As explained in section 2.6.1 the distance will be measure from input and output points of the different processes because the layout is already planned. The distances measured will only include the sequence of the processes and not all the distances between the processes. This is mainly because other distances beside the distance of the process sequence are irrelevant. The different measures were calculated taking into consideration the straight lines between the processes. To measure the straight lines the aisles were considered. The only exception is between the log processing and the log conditioning process because there are outdoor processes so the material handling machine can move freely.

The gluing and assembly process is not included in the measures because it belongs to the press process and the distance between them is irrelevant. As well as with the gluing and assembly the distance from the peeling process to the clipping process is not included because they operate as a single process. Table 4.1 shows the detailed measurements.

Table 4.1. Distances between processes of current layout.

Processes	Distance (meters)
Log Processing → Log Conditioning	24.15
Log Conditioning →Peeling	26.89
Clipping (upper output)→Drying (nº1)	35.33
Clipping (upper output)→Drying (nº2)	44.80
Clipping (lower output)→ Drying (nº1)	18.67
Clipping (lower output)→ Drying (nº2)	14.26
Drying (nº1) → WIP 2	34.81
Drying (nº2) → WIP 2	36.74
WIP 2 → Composer	136.63
Composer→ WIP 1	13.67
WIP 1 → Press (nº1)	110.45
WIP 1 → Press (nº2)	139.46
WIP 2 → Press (nº1)	143.62
WIP 2 → Press (nº2)	172.63
Press (nº1) → WIP 3	18.04
Press (nº2) → WIP 3	33.61
WIP 3 →Dimensional cutting	4.75
Dimensional cutting →Repairing	20.59
Dimensional cutting→ Sanding	44.67
Dimensional cutting→ Storage (finished products)	78.63
Repairing→ Sanding	59.02
Sanding → Storage (finished products)	40.64

In the Table 4.1 the backtracking distances are highlighted in red. Although these are backtracking distances they cannot be removed completely because the processes must still be connected. Thus, these distances will probably be reduced in better design arrangements proposed in section 4.3.2.

In the Table 4.1 there are two clipping processes. In fact the process is only one but the outcomes are arranged in two different sites so the distance was calculated by averaging the different distances from the sites to the next process. The Figure 4.6 shows the example of the distances measured between the clipping and the drying process.

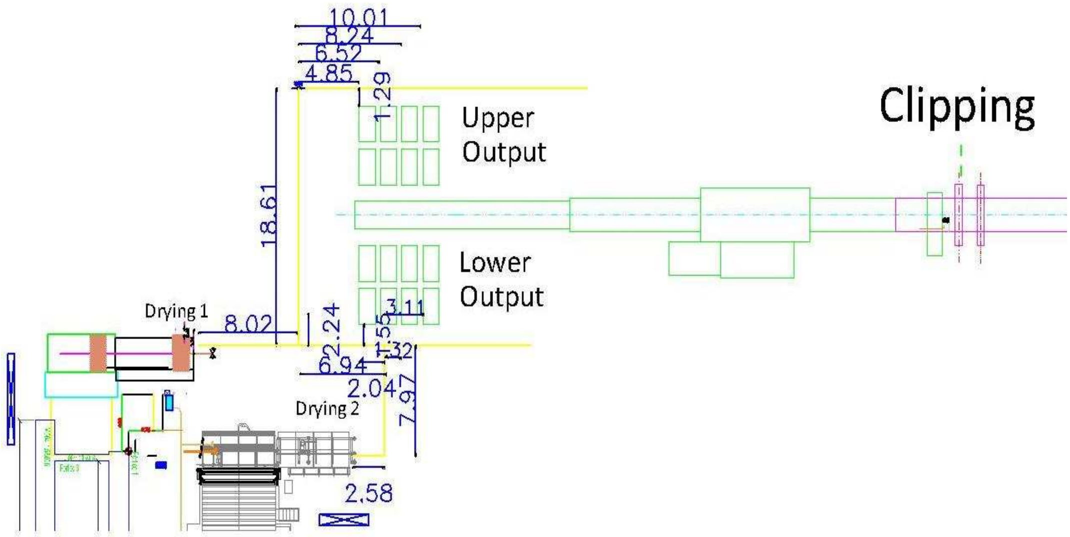


Figure 4.6. Example of distance measurement. ***Source*** **(modified): Urupanel.**

As Figure 4.6 shows, the upper and lower outputs of the clipping machine have four storage devices for the crane fork to lift and carry them to the drying process. In order to calculate the distance an average distance from these four storages to the main aisle is done. For example the average for the upper output is: $\frac{10{,}01+8{,}24+6{,}52+4{,}85}{4} = 7{,}405$. The remaining detailed distances between processes are in Appendix 3.

There are different lengths of the paths according to different specifications. As mentioned in section 4.2 there are different routes for different types of materials. In this case, the processes with two outputs like the clipping, drying and press are merged into one output considering an average of the distances to simplify the comparison with other alternatives proposed in section 4.3.2 and to measure the corresponding paths. The different paths and the length of them are described in Table 4.2. The numbers correspond to the processes identified previously in Figure 4.1.

Table 4.2. Path distances of current layout.

Path	Distance (meters)
1) 1-2-3-4-5-6-9-10-11-12-13-14	424.38
2) 1-2-3-4-5-6-9-10-11-13-14	389.44
3) 1-2-3-4-5-6-9-10-11-14	382.76
4) 1-2-3-4-5-6-7-8-9-10-11-12-13-14	541.16
5) 1-2-3-4-5-6-7-8-9-10-11-13-14	506.22
6) 1-2-3-4-5-6-7-8-9-10-11-14	499.54

As shown in Table 4.2 the longest path corresponds to path 4 that is the path for the randoms or cut veneers that travel the backtracking distance from the work-in process area 2 to the composer process and also from the press nº2 to the work-in process area 3.

In order to evaluate the current layout it is necessary to know the amount of flow among this processes and the cost of transportation of the unit load. As discussed in section 2.4.1 the best technique to measure quantitatively the flow is the from-to chart. This chart is completed with the production summary of the company that is attached in Appendix 4. The time frame considered was the average production of 6 months.. The Figure 4.7 shows the from-to chart.

	From/to (unit load=3 m3)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Log Processing	x	8435,67												
2	Log Conditioning		x	4499,02											
3	Peeling			x	2399,5										
4	Clipping				x	2207,52									
5	Drying					x	1942,62								
6	WIP 2						x	300,33		1642,29					
7	Composer							x	285,31						
8	WIP 1								x	285,31					
9	Press									x	1889,05				
10	WIP 3										x	1889,05			
11	Dimensional cutting											x	944,52	566,71	377,81
12	Repairing												x	944,52	
13	Sanding													x	566,71
14	Storage														x

Figure 4.7. From-to chart.

The movements between the Log Processing, Log Conditioning and Peeling are made by a front loader. Mean while the other moves are made by a crane fork. Both machines can handle

3 m^3 approximately. The company establishes that 3 m^3 is one unit load. It can be appreciated that the most important flows are between the processes 1 and 6 because they handle all the raw material.

The last measure needed to utilize the objective function introduce in section 2.6.1 is the cost of transportation of the unit load. Currently there are five crane forks available for the movement of materials between processes and two front loaders. The cost of operation of the crane fork is 3.1 US$/km and 43 US$/km for the front loader. These costs were estimated by the values that the company pays monthly to rent this machinery. These costs include everything needed to the operation such as the fuel, operator salary and maintenance.

Having the distances and flow amount between processes as well as the cost of transportation defined it is possible to use the equation introduce in section 2.5.1 and calculate its result. The equation is:

$$\min z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} c_{ij} d_{ij}$$

Where "*m* denote the number of departments, f_{ij} denote the flow from department *i* to department *j* (expressed in number of unit loads moved per unit time), and c_{ij} denote the cost of moving a unit load one distance unit from department *i* to department *j*" (Tompkins *et al.*, 2003). The last variable is d_{ij} that it is the distance from department *i* to department *j*.

The Table 4.3 shows the different costs incurred in the different routes that materials can follow. There are two main paths: from the Log processing to the Work-in process area 2 and from the Press to the Dimensional cutting. The numbers correspond to the processes introduce in Figure 4.1.

Table 4.3. Paths and costs of current layout.

Path	Cost (US$/monthly)
1) 1-2-3-4-5-6	29,968.54
a) 6-9	4,025.14
b) 6-7-8-9	1,249.08
2) 9-10-11	1,651.41
a) 11-12-13-14	1,522.49
b) 11-13-(14)	749.37
c) 11-14	460.46
TOTAL	**39,269.5**

The Table 4.3 shows that the most important cost is incurred in the first processes mainly because of the utilization of the front loader that is considerably more expensive than the crane fork. Also because in the early stages the entire raw material is moved not like in the final processes were the amount of flow moved is less due to efficiency issues. In Path 2b the cost between process 13 and 14 is not included because is already added in path 2a.The total monthly cost incurred in transportation between the processes is US$ 39,269.5.

Productivity evaluation

As mentioned in section 2.5 the productivity is the ratio of outputs against inputs. To establish a reasonable comparison the inputs are specified to appreciate were the main differences are. Table 4.4 shows the different resources utilised and the value of them. Further information is provided in Appendix 5.

Table 4.4. Resources for current layout.

Resource	Monthly Values
Output:	
• **Production**	5,600 (m^3)
Inputs:	
• **Labour**	US$ 140,400
• **Capital:**	
- Raw materials	US$ 595,298
- Machines maintenance	US$ 4,000
- Material handling equipment (transportation)	US$ 39,270
- Electric energy	US$ 88,000
- Others	US$ 42,000
Total Labour	US$ 140,400
Total Capital	US$ 768,568
TOTAL Input	**US$ 908,968**

The values for the inputs are considered in a period of one month. The inputs are in terms of operating resources needed to produce the 5,600 m^3 monthly and do not include the purchase value of machines and others.

The calculation of the multi-factor productivity is useful to establish a reasonable comparison between the alternatives proposed and the influence of the facility layout factors. The formula below shows the calculation of the current productivity:

$$Productivity = \frac{Production}{Labour + Capital} = \frac{5{,}600\ m^3}{140{,}400 + 768{,}568} = 0.00616083$$

This value shows that 616.083 m^3 are monthly made with the input of US$ 100,000. This number by itself is not so representative and the importance of it lies in the possibility to compare these results with other alternatives. In the next section plant layout alternatives are generated.

4.3.2 Plant layout alternatives

In this section alternatives regarding the configuration of the processes and the flow of materials are addressed. These alternatives are produced using a variation of the systematic layout procedure. As explained in section 4.1, the space relationship diagram and the final layout design are produced by the software AutoCAD.

The main two inputs are the from-to chart and the activity relationship chart mentioned in section 2.4.1.1 and 2.4.1.2 respectively. The from-to chart was introduce in the current state analysis in Figure 4.7. The construction of the activity relationship chart was based on the information in the from-to chart as well as the information provided in the interviews. The activity relationship chart can be found in Appendix 6. Furthermore the practical limitations are discussed below.

Practical limitations

As mentioned in section 4.3.1 the current layout face some problems that can be solved or at least decrease their impact on productivity and costs by rearranging the processes. The rearranging is not so simple; many issues must be considered to evaluate the feasibility of these changes. These limitations are highlighted by the company, especially by the individuals interviewed.

The main issues discussed in the interviews were regarding the difficulty to disarm some processes for afterwards armed them in another location. This difficulty exists mainly because the complexity of the machines is high so the installation of some of them could last for at least three to four months. This is the case of the peeling process. Another process that shares the same problem is the drying process. Furthermore, the ducts from the drying process that goes to the boiler are also difficult to translate and problems with the pressure and other variables may arise if they are moved. The pressing process is also very difficult to move because of the foundations needed for the two presses as well as for the ducts that come from the boiler. In addition, the pressing process and the drying process constitute the heart of the production so any changes in these processes will affect directly in the production.

Regarding the outside processes that are the Log processing and Log conditioning the interviewees suggested not to move them because of the heavy structure they have, especially the Log conditioning. Other areas, like work-in process areas can be moved freely. However, regarding the storage area there was no agreement among the interviewees. Jose L. Saenz and Rodrigo Correa suggested leaving the storage area in the same place mainly because the exit of finished goods towards the truck loading area is there. However, Fabrizio Blengio did not mention this issue as a restriction. He expressed that it could be rearrange. In summary, the processes that are feasible to move are: all work-in process areas, composer, dimensional cutting, repairing and sanding with an exception of the storage area if it is necessary. In the next section the generation of the alternatives layout and the evaluation of them is addressed.

4.3.2.1 Alternative 1

Taking into consideration both the from-to chart and the activity relationship an alternative arrangement for the current state is introduced. In this alternative the composer process, dimensional cutting, repairing and sanding process are changed. The Figure 4.9 shows these changes.

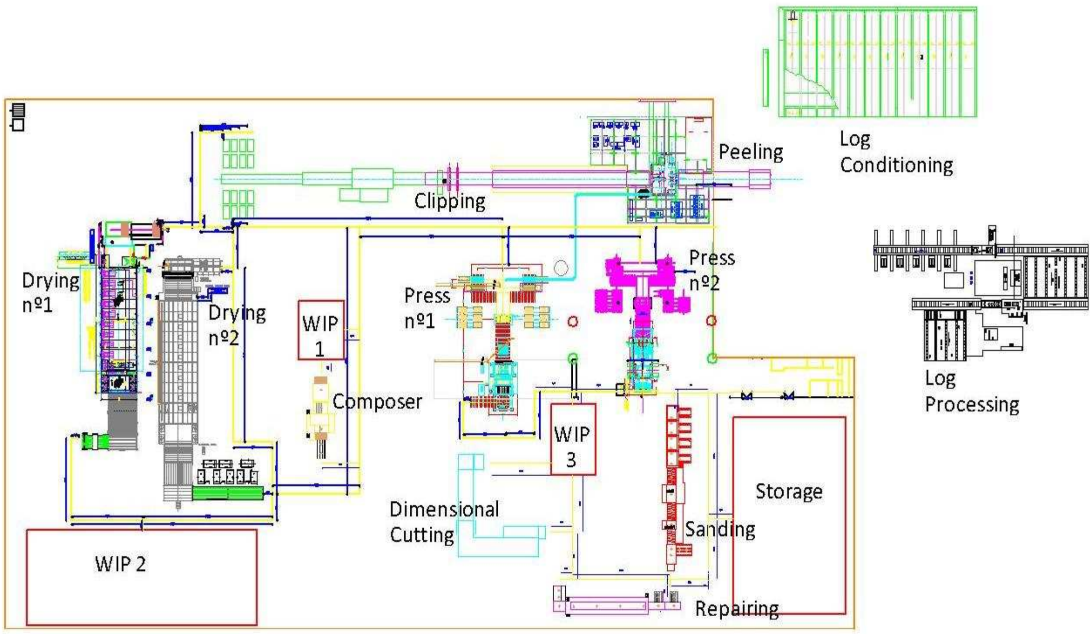


Figure 4.8. Plant layout alternative 1. *Source* (modified): Urupanel.

As Figure 4.8 shows the composer has been moved near the pressing process and also near the work-in process area 2. Also the repairing process has been moved near the sanding. The different changes and their implications are explained in the next subsections.

Cost evaluation

In order to assess this alternative the different paths of the materials explained in Table 4.5 are calculated again using this alternative arrangement. The information needed is only the distances among processes because the amount of flow and the cost of transportation remain the same. The detailed measurements of these new distances are in Appendix 7. The Table 4.5 shows the new distances that are highlighted in blue.

Table 4.5. Distances between processes of alternative 1.

Processes	Distance (meters)
Log Processing → Log Conditioning	24.15
Log Conditioning → Peeling	26.89
Clipping (upper output)→Drying (nº1)	35.33
Clipping (upper output)→Drying (nº2)	44.80
Clipping (lower output)→ Drying (nº1)	18.67
Clipping (lower output)→ Drying (nº2)	14.26
Drying (nº1) → WIP 2	34.81
Drying (nº2) → WIP 2	36.74
WIP 2 → Composer	67.87
Composer → WIP 1	1.95
WIP 1 → Press (nº1)	61.59
WIP 1 → Press (nº2)	90.6
WIP 2 → Press (nº1)	143.62
WIP 2 → Press (nº2)	172.63
Press (nº1) → WIP 3	43.22
Press (nº2) → WIP 3	13.75
WIP 3 →Dimensional cutting	12.91
Dimensional cutting → Repairing	16.66
Dimensional cutting → Sanding	51.18
Dimensional cutting → Storage (finished products)	60.13
Repairing → Sanding	17.67
Sanding → Storage (finished products)	24.53

With the corresponding distances from this new arrangement of the flow, the calculation of the paths and their total distances is done. This measurement is done to highlight the differences among the two layout designs. The Table 4.6 shows the paths and their distances.

Table 4.6. Path distances of alternative 1.

Path	Distance (meters)
1) 1-2-3-4-5-6-9-10-11-12-13-14	373.46
2) 1-2-3-4-5-6-9-10-11-13-14	365.78
3) 1-2-3-4-5-6-9-10-11-14	374.73
4) 1-2-3-4-5-6-7-8-9-10-11-12-13-14	361.25
5) 1-2-3-4-5-6-7-8-9-10-11-13-14	378.1
6) 1-2-3-4-5-6-7-8-9-10-11-14	362.52

The new distances for the paths are considerably less than the distances from the current layout design. For example, in path 4 there was a reduction of a 33.25% of the total distance compared to the current layout. In order to measure the impact of this new flow arrangement the objective function will be again applied to the paths and compare the results with the previous design. The Table 4.7 shows these results.

Table 4.7. Path and costs of alternative 1.

Path	Cost (US$/monthly)
1) 1-2-3-4-5-6	29,968.54
a) 6-9	4,025.14
b) 6-7-8-9	572.28
2) 9-10-11	1,212.06
a) 11-12-13-14	718.07
b) 11-13-(14)	449.57
c) 11-14	352.12
TOTAL	**37,297.78**

In this design the total monthly cost for the transportation of the materials is US$ 37,297.78. This amount is US$ 1,971.72 less than the cost of the current layout. In addition, the annual saving with this layout design alternative will rise to US$ 23,660.64 that represents a reduction of 5.02% of the annual cost of transportation. In the next subsection the impact on productivity is evaluated.

Productivity evaluation

In terms of productivity this alternative represents an improvement. This is because the output (production) is the same, however the inputs decrease. This reduction will imply a higher productivity. The Table 4.8 shows the difference on the resources that are needed in this alternative.

Table 4.8. Resources for plant layout alternative 1.

Resource	Monthly Values
Output:	
• **Production**	5,600 (m^3)
Inputs:	
• **Labour**	US$ 140,400
• **Capital:**	
- Raw materials	US$ 595,298
- Machines maintenance	US$ 4,000
- Material handling equipment (transportation)	US$ 37,298
- Electric energy	US$ 88,000
- Others	US$ 42,000
Total Labour	US$ 140,400
Total Capital	US$ 766,596
TOTAL Input	**US$ 906,996**

As Table 4.8 shows the decrease in the cost of transportation is highlighted in red. This reduction that was established previously in Table 4.7 affects the total capital input.

Consequently the productivity with this alternative will increase. The equation below shows the calculation of the productivity.

$$Productivity = \frac{Production}{Labour + Capital} = \frac{5{,}600\ m^3}{140{,}400 + 766{,}596} = 0.00617423$$

This means that with the same US\$ 100,000 it is possible to produce 617.423 m^3 of plywood. In comparison with the current layout the difference is very low. The increment in productivity is 0.22%. In order to evaluate a higher increase in productivity and reduction of costs a second alternative is generated, explained in the next section.

4.3.2.2 Alternative 2

In this design the work-in process area 2 was move because it compromises a large amount of flow between the dryers, the composer and the press. Also the composer and work-in process area 1 were relocated not further in comparison to layout design alternative 1 because it proved to bring a great cost reduction. Figure 4.9 shows the alternative.

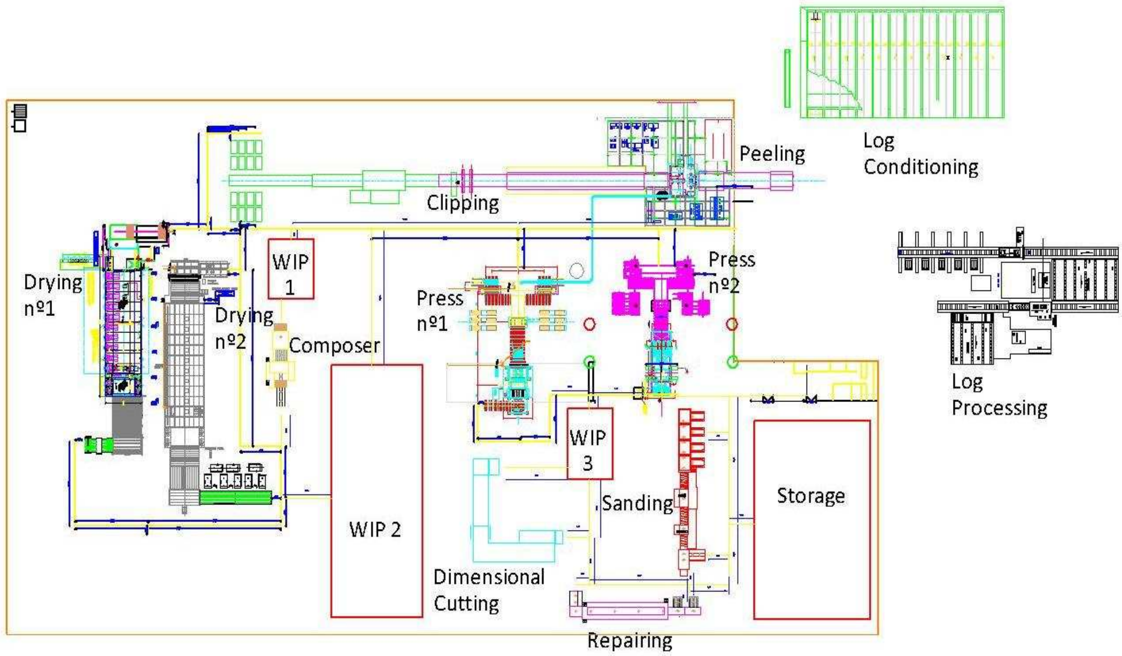


Figure 4.9. Plant layout alternative 2. *Source* (modified): Urupanel.

As mentioned, the work-in process area 2 was relocated near the pressing process and also near the composer. The relevance of this new rearrangement is discussed in the next subsections that will evaluate the cost reduction and the impact on productivity of this new design.

Distances and costs

Accordingly to this new layout, the distances must be recalculated to assess the impact of these new changes on the final cost. Some distances are the same as in the previous layout because of the restrictions mentioned on the practical limitations. The detailed measurements are in Appendix 8. The distances for this new layout design are listed in Table 4.9.

Table 4.9.Process distances of alternative 2.

Processes	Distance (meters)
Log Processing → Log Conditioning	24.15
Log Conditioning → Peeling	26.89
Clipping (upper output)→Drying (nº1)	35.33
Clipping (upper output)→Drying (nº2)	44.80
Clipping (lower output)→ Drying (nº1)	18.67
Clipping (lower output)→ Drying (nº2)	14.26
Drying (nº1) → WIP 2	76.49
Drying (nº2) → WIP 2	12.52
WIP 2 → Composer	26.82
Composer → WIP 1	4.37
WIP 1 → Press (nº1)	56.67
WIP 1 → Press (nº2)	85.18
WIP 2 → Press (nº1)	64.40
WIP 2 → Press (nº2)	93.41
Press (nº1) → WIP 3	43.22
Press (nº2) → WIP 3	13.75
WIP 3 →Dimensional cutting	12.91
Dimensional cutting → Repairing	16.66
Dimensional cutting → Sanding	51.18
Dimensional cutting → Storage (finished products)	60.13
Repairing → Sanding	17.67
Sanding → Storage (finished products)	24.53

It can be appreciated that there are some significant distance reduction in comparison to the layout design alternative 1. For example there is a reduction of 50.14 m was achieved in the distance from the work-in process area 2 to the composer. Remembering the current layout design this distance was 136.63 m and mostly of it was a backtracking movement. Now in this alternative this distance is reduced to 26.82 m. These reductions can be easily compared in the distances of the existing paths. Table 4.10 shows this information.

Table 4.10. Path distances of alternative 2.

Path	Distance (meters)
1) 1-2-3-4-5-6-9-10-11-12-13-14	302.97
2) 1-2-3-4-5-6-9-10-11-13-14	319.82
3) 1-2-3-4-5-6-9-10-11-14	304.24
4) 1-2-3-4-5-6-7-8-9-10-11-12-13-14	326.18
5) 1-2-3-4-5-6-7-8-9-10-11-13-14	343.03
6) 1-2-3-4-5-6-7-8-9-10-11-14	327.45

Taken into consideration again path 4, the reduction of this alternative in comparison to the current layout design is of 39.73% and 9.71% less than layout design alternative 1. Table 4.11 shows the corresponding costs associated to the paths.

Table 4.11. Path and costs of alternative 2.

Path	Cost (US$/monthly)
1) 1-2-3-4-5-6	30,231.41
a) 6-9	2,008.56
b) 6-7-8-9	457.83
2) 9-10-11	1,212.06
a) 11-12-13-14	718.07
b) 11-13-(14)	449.57
c) 11-14	352.12
TOTAL	**35,429,62**

Even though that in this alternative the cost of path 1-6 is slightly higher than the current state and the alternative 1; the total cost is minor. With this alternative the annual saving increases to US$ 46,078.6 that means a 9.78% less than the current layout design. The next step is to evaluate the impact on productivity.

Productivity

As well as with the alternative 1 this new design will influence on the productivity of the process. In this design the reduction of costs is higher so the impact on productivity must be greater. Table 4.12 shows the new values for the resources.

Table 4.12. Resource for plant layout alternative 2.

Resource	Monthly Values
Output:	
• **Production**	5,600 (m^3)
Inputs:	
• **Labour**	US$ 140,400
• **Capital:**	
- Raw materials	US$ 595,298
- Machines maintenance	US$ 4,000
- Material handling equipment (transportation)	US$ 35,430
- Electric energy	US$ 88,000
- Others	US$ 42,000
Total Labour	US$ 140,400
Total Capital	US$ 764,728
TOTAL Input	**US$ 905,128**

The Table 4.12 shows that as well as with alternative 1 the reduction occurs in the transportation costs due to the rearrangement of the processes. This reduction in costs is introduced in Table 4.11. The productivity in this case is:

$$Productivity = \frac{Production}{Labour + Capital} = \frac{5{,}600\ m^3}{140{,}400 + 764{,}728} = 0.00618697$$

With this alternative it is possible to produce 618.697 m^3 with the same US$ 100,000. In this case the increase on productivity compared to the current design is of 0.42%. Again these result is very low, however the annual costs savings for this alternative are US$ 46,078.6.

A third alternative was not developed because of the limited space to move the processes. With the changes made from the alternative 1 and alternative 2 the remaining space to try relocating the processes is very small and the changes would not be relevant mainly because the processes would be relocated very closely to positions evaluated in the previous alternatives.

4.3.3 Plant layout factor results

Although some changes in the configuration of the processes were not substantial the impact on productivity and mainly in cost reduction was. Table 4.13 shows the results for the different alternatives proposed.

Table 4.13. Plant layout analysis results.

Layout Design	Total cost of transportation (US$/annually)	Transportation cost reduction	Productivity (m^3 per US$100,000)	Productivity increase (%)
Current State	471,234	---	616.083	---
Alternative 1	447,573	5.02%	617.423	0.22%
Alternative 2	425,155	9.78%	618.697	0.42%

As Table 4.13 shows the better alternative is the alternative 2. This new design will reduce the annual costs of transportation to US$ 425,155 that represents a 9.78% reduction. . The variation in costs is denoted in Figure 4.10. The impact on the total operating costs is discussed in section 4.5.

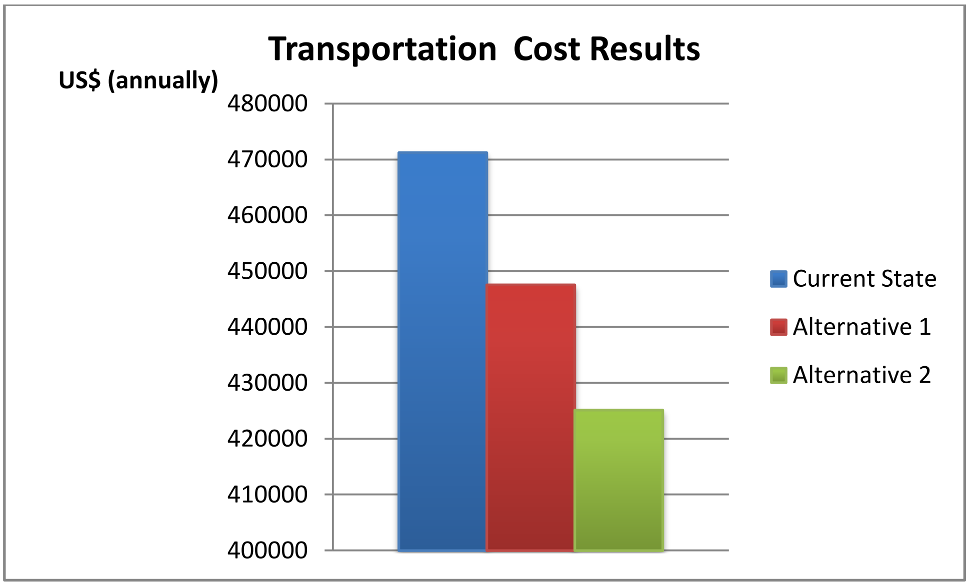


Figure 4.10. Transportation cost results.

As well as with the costs the two alternatives proposed have a positive contribution regarding the productivity. In this case the higher productivity rises up to 618.697 m^3/US$ for alternative 2. The difference is plotted in Figure 4.11.

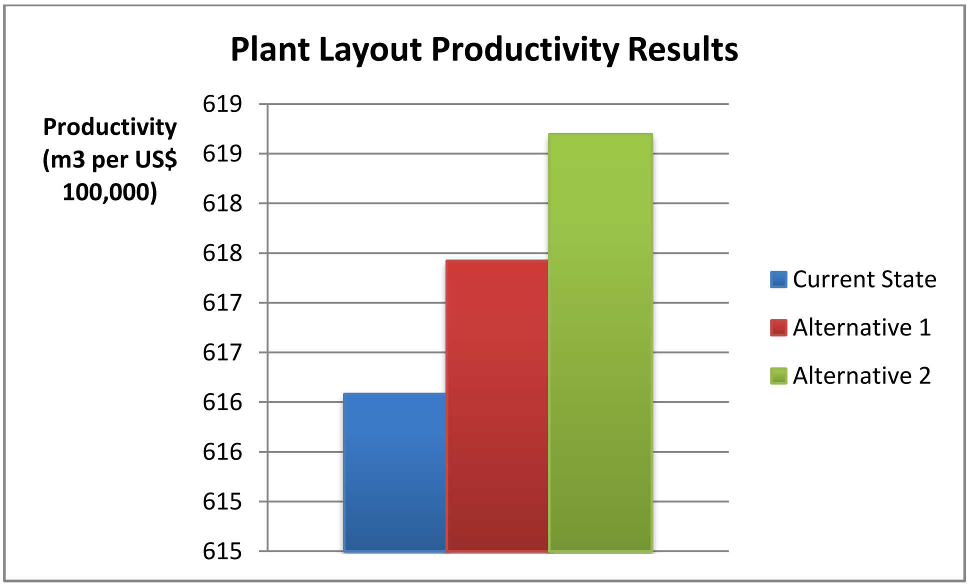


Figure 4.11. Plant layout productivity results.

Although there is a positive variation in the productivity, it is very low as 0.22% and 0.42% for alternative 1 and 2 respectively. On the contrary, the cost reduction is significant but with both alternatives the cost of relocation of the processes was not considered. Taken into consideration alternative 2 which has the greater cost savings and impact on productivity, an estimation of the relocating cost was made. Table 4.14 shows this estimation.

Table 4.14. Relocation costs.

Relocation	Cost Estimation (US$)
Composer	5,000
Repairing	3,500
Sanding	4,000
Work-in process area 1	--
Work-in process area 2	--
Work-in process area 3	--
TOTAL	**12,500**

The cost of moving the work-in process areas is not included because there is not a structure that surrounds these areas so the rearrangement of them does not incur in any cost to the company. The total sum of US$ 12,500 can be easily covered with a year of savings due to the implementation of alternative 2. This analysis has moved the study one step forward towards answering the research question proposed at the beginning of this research. In the next section material handling factor will be approached and discuss in order to evaluate its impact in productivity and cost reduction and compare it with the flow analysis just discussed.

4.4 Material handling factor analysis

4.4.1 Current state

As described in section 4.2 the current plywood process has two main material handling equipments: the crane forks and the front loaders. The two front loaders are used to transport the logs from the log processing to the log conditioning area. Afterwards, these front loaders introduce the logs in a small conveyor belt towards the peeling process. The peeling and all the remaining processes are in the warehouse so there is not possibility for the front loader to be used in any other process.

When the peeling process is done, the logs are automatically moved to the clipping process. Both peeling and clipping processes act as a single process and the movement between them cannot be modified. After the clipping process all the remaining transportation of the veneers is done by using crane forks. There are five crane forks currently in use. Figure 4.12 shows a diagram of the utilization of the front loaders and the crane forks. Crane forks paths are highlighted in blue and front loaders path in yellow.

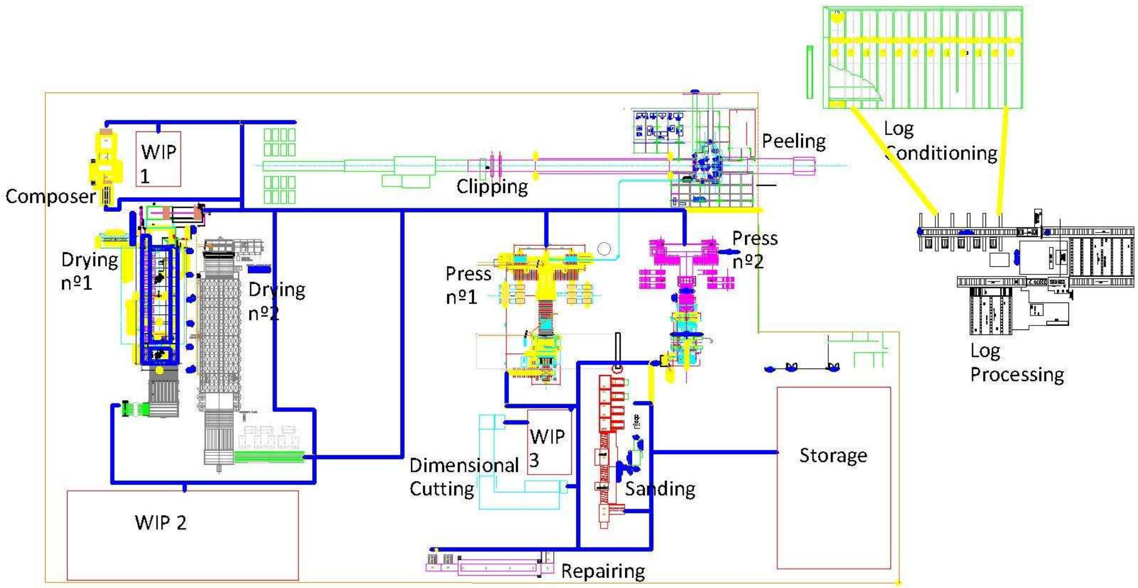


Figure 4.12. Utilisation of front loaders and crane forks. Source (modified): Urupanel.

The Figure 4.12 shows that there is one crane fork utilised between the clipping and drying process. The second crane fork is used between the two outputs of the drying process and the work-in process area 2. A third crane fork is utilised to move the veneers towards the composer and the press process. The fourth one transports the pressed veneers to the work-in process area 3 and to the remaining processes (dimensional cutting, repairing and sanding). The last crane fork is utilised in the storage area two organize the packaged product in the storage and inside the containers that will be loaded into the trucks to be shipped. Although in the diagram the crane forks appear to be assigned to specific processes in fact many times the crane forks move freely to help in other processes.

Even though the transportation is done by the crane forks there must be a system to stack the veneers so that the crane fork can load them easily. The stacking process is done automatically in all the processes except for the drying process. In this case, the dried veneers enter a rounded platform that rotates so that three operators can stack the veneers in customized trolleys and the crane fork can load the stack. Figure 4.13 shows how it works.

Figure 4.13. Stacking in dryer output. ***Source:*** **Urupanel.**

As Figure 4.13 shows an operator is taking of the veneer from the platform and putting it in the trolley. This method is used in both dryers, adding a total of six operators in charge of stacking the veneers. This number of operators will directly affect the Material Handling Labour Ratio explained in section 2.4.2. This ratio measures the personnel assigned to material handling duties in comparison to the total plant operating personnel. The Table 4.15 shows the amount of workers per process and transportation duties. This amount of workers corresponds to one shift.

Table 4.15. Number of operators per activity.

Activity	Number of Operators
Process:	
• Log Processing	3
• Log Conditioning	2
• Peeling	2
• Clipping	1
• Drying	2
• Composer	1
• Press	16
• Dimensional Cutting	3
• Repairing	4
• Sanding	2
• Storage (Packaging)	2
	1
Material handling duties:	
• Front Loader	2
• Crane Fork	5
• Stacking (drying process)	6
TOTAL	52

Taking into consideration one shift, the Material Handling Labour Ratio is:

$$MHLR = \frac{Personnel\ Assigned\ to\ Material\ Handling\ Duties}{Total\ Plant\ Operating\ Personnel} = \frac{13}{52} = 0.25$$

This ratio is less than 1 and inferior to 0.30 so, as argued by Sule (2009), is a proper value. However in the next section the improvement of this ratio will be analysed. The other ratio introduced in section 2.4.2 was the Storage Space Utilisation. This ratio measures the storage space occupied versus the total available storage space. The measurement of this ratio is difficult and even more complicated in industries like plywood. This is because the total available storage space is calculated over the analysis of the demand and always is considerably bigger than the storage space occupied because they cannot afford to have the product outside the warehouse because of its specification related to humidity. The Table 4.16 shows the storage space.

Table 4.16. Storage Space.

Storage Space	Area (m^2)
Storage Space Occupied	
• Work-in process area 1	110.38
• Work-in process area 2	927.12
• Work-in process area 3	130.72
TOTAL	**1,168.22**
Total Available Storage Space	
• Storage space occupied	1,168.22
• Area 4	985.40
• Area 5	324.37
• Area 6	683.93
TOTAL	**3,161.92**

As shown in Table 4.16 there are three new storage areas that could be utilize. The detailed measurement of these areas can be found in Appendix 9. Then the Storage Space Utilisation is:

$$Storage\ Space\ Utilisation = \frac{1{,}168.22}{3{,}161.92} = 0.369$$

This value is far from 1 that was suggested by Sule (2009) as a proper value where the storage space has been used efficiently. However, as explained previously, this value is not so representative in this type of industry. Furthermore, this ratio is not included in the alternative section because it depends on the production and work-in process of materials that are not modified.

In the next section alternatives to the material handling factor are discussed emphasising on the reduction of personnel assigned to material handling duties and also the possibility of introduce a new unit load.

4.4.2 Alternatives

In this section alternatives to the material handling factor are addressed. As mentioned in the previous section the main opportunities to develop alternatives are in the reduction of the Material Handling Labour Ratio (MHLR) and the possibility to implement a new unit load that could benefit the process.

Regarding the MHLR the main issue is to reduce the number of workers that are only assigned to material handling duties and that do not transform or increase the value of the product. Therefore the cost on these operators is not justified from the point of view of adding value to the final product. There are currently two material handling activities that do not add value: transportation with the front loader and crane fork and the stacking in the output of the drying process. The first activity is addressed when the unit load design is argue because there is a direct relationship with this concept. This relationship s based on that the unit load size defines the necessary equipment for transportation.

The second material handling activity has a possible solution. This solution implies to eliminate the current six operators that manually stack the veneers for the crane fork to load them by an automatic stacking machine. This machine can be located in the middle of the two dryers output so that a conveyor belt can consolidate the veneers from the two dryers into a single machine. The Figure 4.14 shows an automatic stacking machine.

Figure 4.14. Automatic stacking machine. ***Source:*** **Edward B. Mueller Company.**

Therefore, the veneers that finish the drying process are arranged by this machine. The utilisation of this system would reduce the number of workers by six and leave the process of stacking completely automated. This reduction will affect the MHLR and decrease it to the value of $MHLR = \frac{7}{52} = 0.135$. This value is only for comparison, it does not have a greater mean.

The cost reduction implied by the reduction of these six workers per shift will reduce considerably the labour input establish by the company. However, the cost of the automatic stacker is high. If the assumption of buying a new automated stacker at an "average" price (more or less the market price, will depend on the brand and other specifications) is made, the results and benefits would be the followings:

Table 4.17. Unit costs.

Unit	Cost
Automatic Stacker	US$ 2,500,000
6 workers	US$ 194,400 (annually)

Table 4.17 shows that the cost of the automatic stacker is equivalent to approximately 13 years of salary of the six operators. The annual salary was calculated on the basis that six workers are needed per shift with three shifts per day and the monthly cost of one operator is US$ 900.

The remaining issue concerning the material handling system is the unit load. The current unit load is 3 cubic meters which is the capacity of both the crane fork and the front loaders. The redesign, if possible, of the unit load could bring benefits to the process in terms of less equipment needed or fewer operators. However, in this particular case the modification of the unit load appears infeasible because of the current conditions of the layout. This statement is based on these arguments:

- Increasing the size of the unit load would need the use of bigger equipment to replace the crane forks. These equipments would not fit in the aisle and also will complicate the loading and unloading of the veneers that will translate into longer operating times. Furthermore the loading of the trucks must be done by crane forks.

- Decreasing the unit load will imply the utilisation of customized trolleys that will increase the number of workers needed for material handling duties. This will imply to hire more workers and increase the cost. Furthermore, having at least 10 workers moving around with customize trolleys could increase the number of accidents and damage to the products.

These two arguments support the idea that the actual method of transportation between the processes (front loaders and crane forks) is the best way to provide a feasible solution to the material movements. Furthermore this analysis was shared with the company and the interviewees agreed with the limitations of a different unit load.

Productivity

In terms of productivity the reduction of personnel proposed in the previous subsection will directly affect the labour input. Thus the productivity will vary. The Table 4.18 shows the new values for the labour and total values.

Table 4.18. Resources for material handling alternative.

Resource	Monthly Values
Output:	
• **Production**	5,600 (m^3)
Inputs:	
• **Labour**	US$ 124,200
• **Capital:**	
- Raw materials	US$ 595,298
- Machines maintenance	US$ 4,000
- Material handling equipment (transportation)	US$ 39,270
- Electric energy	US$ 88,000
- Others	US$ 42,000
Total Labour	US$ 124,200
Total Capital	US$ 768,568
TOTAL Input	**US$ 892,768**

The machine maintenance costs remains the same because it is an approximately value used by the company and the new stacking machine would not affect this value. On the contrary, the reduction of six workers will affect directly the labour input and the productivity. To compare these results with the current state the same productivity calculation is done.

$$Productivity = \frac{Production}{Labour + Capital} = \frac{5{,}600}{124{,}200 + 768{,}568} = 0.00627263$$

With the material handling alternative it is possible to produce 627.263 m^3 with the US$ 100,000. This value is higher than the other two alternatives proposed for the flow analysis. This is mainly because of the US$ 900 monthly costs per worker per shift that the company incurs to handle the veneers at the output of the dryers that with this alternative is terminated.

4.4.3 Material handling factor results

In summary, the best material handling alternative is to reduce the currently six workers that handle the stacking in the drying process for an automatic stacking machine. This machine will reduce the operators needed in the plant and therefore reduce the costs. The Table 4.19 shows the results for the material handling analysis.

Table 4.19. Material handling results.

Layout Design	Total Labour Cost (US$/annually)	Labour Cost Reduction	Productivity (m^3 per US$100,000)	Productivity increase (%)
Current State	1,684,800	---	616.083	---
Alternative	1,490,400	11.54%	627.263	1.81%

The Table 4.19 shows that the cost reduction rises to US$ 194,400 annually. The results are denoted in Figure 4.15 that highlights the impact of the alternative regarding possible cost savings for the company.

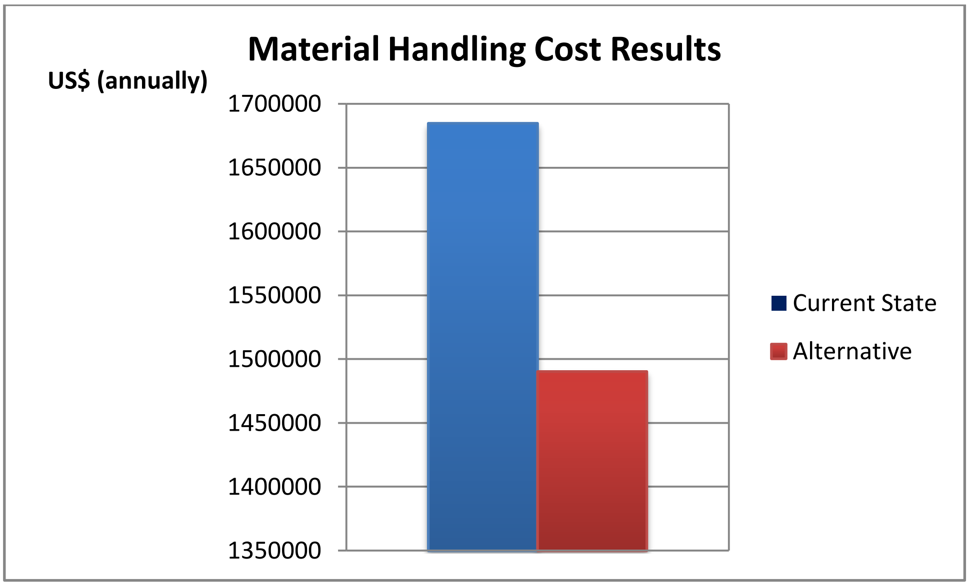


Figure 4.15. Material handling cost results.

Even though the costs savings appear to be very significant these cost does not include the purchase of the new machine that would make possible the reduction of the six workers. However, the assumption made explains that the cost of the machine is balanced with the annual savings on the labour input.

On the other hand, the productivity increases to 627.263 m^3 per US$ 100,000 that represents a 1.81% productivity variation. This variation is denoted in Figure 4.16.

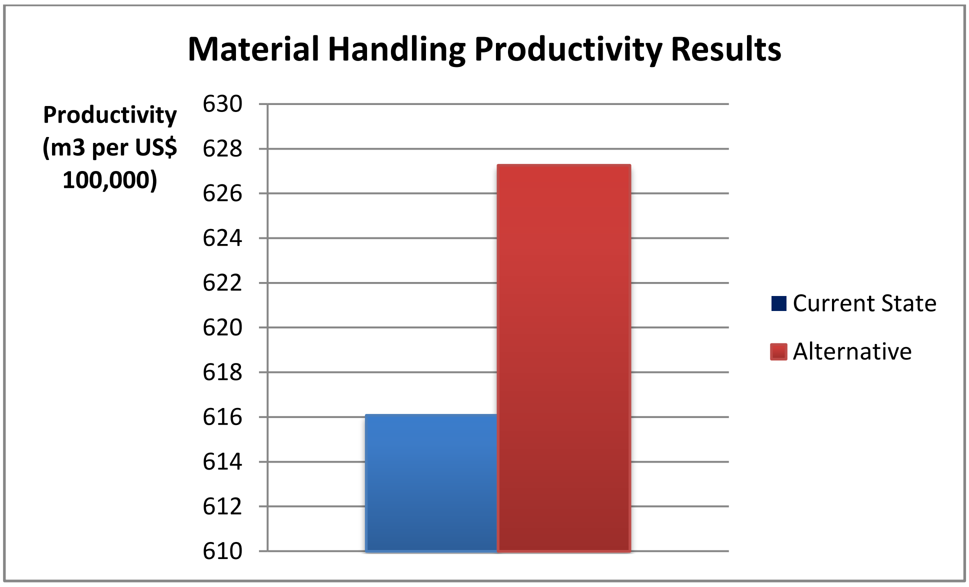


Figure 4.16. Material handling productivity results.

As well as with the costs the productivity with the material handling alternative increases. This increment is greater than the one from the plant layout alternative. In the next section the results from both factors are compared to provide the necessary evidence to determine which factor has the greater impact on process productivity and costs.

4.5 Results and recommendations

The facility layout factors analyses exposed different results for the impact on process productivity and cost reduction. In addition, the analysis revealed other implications regarding the facility layout objectives introduced in the literature review. These results and recommendations to the company are discussed below.

The first finding that can be obtained from the analysis is the individual impact of the facility layout factors in cost reduction. Plant layout factor analysis shows that cost savings can be achieved by the rearrangement of the processes. This cost reduction is accomplished due to the minimisation of the distances between the processes and therefore the reduction in the cost of transportation. On the other hand, material handling factor analysis also proves to have a positive impact on cost reduction. This impact is mainly due to the minimisation of the labour input, as a consequence of reducing the number of workers. The cost reduction achieved is higher than the one from the plant layout factor as it is shown in Table 4.20.

A second finding relates to the impact of these two factors on process productivity. As well as with cost reduction, both factors proved to have a positive impact on this issue. The Table 4.20 shows the cost reduction and impact of the facility layout factors.

Table 4.20. Analysis results.

	Total annual costs (Labour + Capital)	Cost reduction (US$/annual)	Productivity (m^3 per US$ 100,000)	Productivity increase (%)
Current State	10,907,616	---	616.083	---
Plant layout analysis	10,861,536	46,079	618.697	0.42%
Material handling analysis	10,713,216	194,400	627.263	1.81%

Previous authors, discussed in the literature review, did not mention any possible range of improvement neither in productivity or cost reduction for the plant layout factor. Only the relationship between them was highlighted. This analysis proves this impact and brings out a quantification of the relationship between plant layout factor and process productivity and costs. The impact on cost reduction is high because with the simple movement of some processes, with a minor cost to the company, would be responsible for an annual cost reduction of US$ 46,079. On the contrary, the impact on process productivity is very low. This is mainly due to the minor percentage of improvement, 0.42%, achieved by this factor. Figure 4.17 shows both impacts.

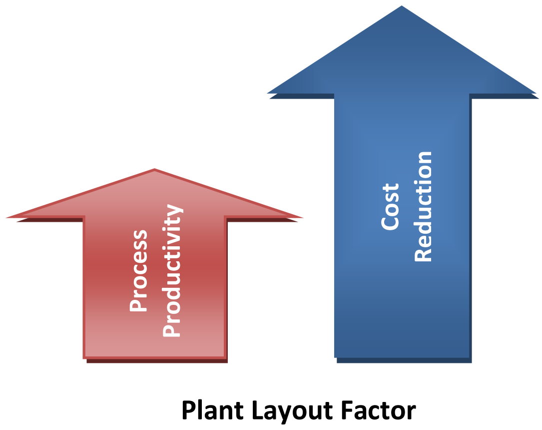


Figure 4.17. Plant layout factor impact.

The Figure 4.17 represents the impact of plant layout over process productivity and costs. It verifies the comments mentioning that plant layout factor has a very low impact on productivity but a high impact on cost reduction. This result answers the subsidiary question regarding the impact of plant layout factor over the process productivity and costs.

In the case of material handling factor previous authors did mentioned a quantification of possible cost reductions. Tompkins *et al.* (2003) suggested that the cost reduction due to material handling improvement could be in the range between 10% and 30%. This affirmation is contrasted in this study because material handling cost savings rise to 1.81% of the total operating costs. This is mainly due to high costs incurred in raw materials that make the cost savings percentage seem irrelevant. However, as irrelevant as this number can appear, it represents a great reduction of costs that rises to an annual saving of US$ 194,400.

As well as with plant layout factor, the impact on process productivity was not specified for material handling. The analysis shows that this factor could be responsible for an increase of 1.81% of productivity. The impact on productivity exposed in this analysis for the material handling factor is considered very low. Figure 4.18 shows both impacts.

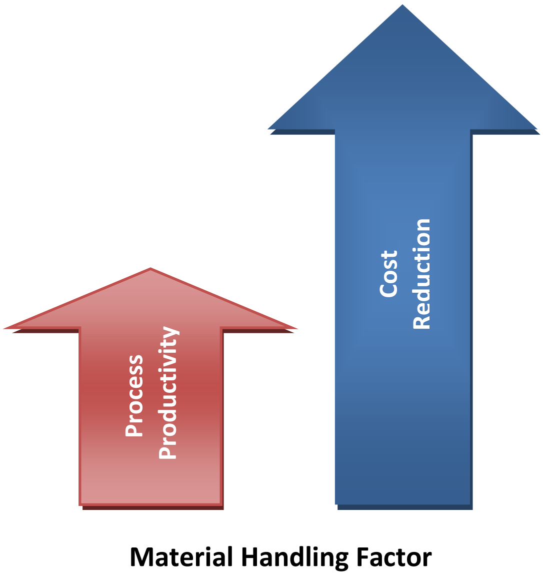


Figure 4.18. Material handling factor impact.

The impact over process productivity is very low. However the impact on cost reduction is high and represents a substantial cost reduction. This result answers the subsidiary question regarding the impact of material handling factor.

Regarding the research question stated at the beginning of this study, the analysis provides a real comparison between the factors. In terms of cost reduction, material handling factor rises as the one with the greater impact. Figure 4.19 shoes the comparison.

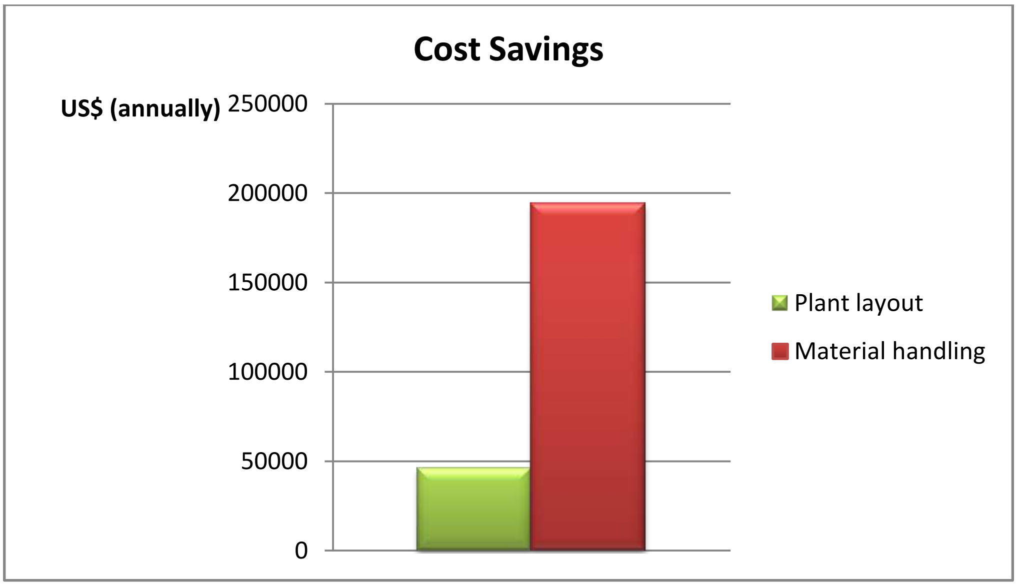


Figure 4.19. Cost savings.

It can be appreciated in Figure 4.17 how material handling factor is responsible for a higher amount of annual cost savings. This is mainly due to the reduction of costs in the labour input. The other parameter in comparison is productivity. In this case, material handling factor also proves to have the greatest impact. Figure 4.20 shows the comparison between the factors.

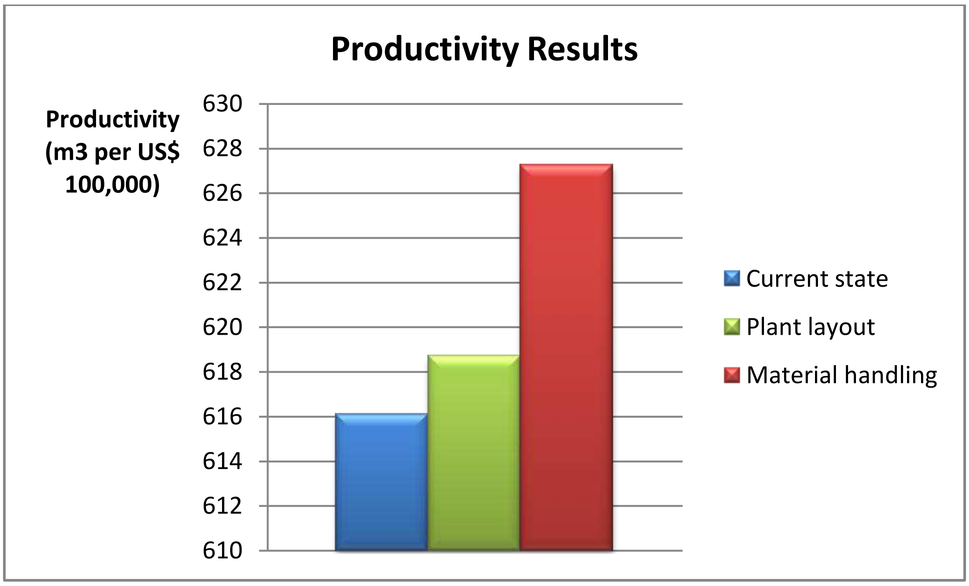


Figure 4.20. Productivity results.

Although the impact for material handling is greater, this impact is considered to be very low. With the comparison of both factors the research question established is answered. Material handling factor emerges as the responsible of the greatest individual contribution towards achieving cost reduction an improvements over process productivity. Consequently if the company would need to choose a factor to modify the obvious answer would be to modify the material handling factor. However, the modification of the plant layout factor could bring additional benefits from a lower investment. With the implementation of the modifications of both factors the company could have an annual saving of US$ 240,479.

As established in section 1.3 the aim of this study was to evaluate the impact of facility layout design on process productivity and cost reduction. With the two factor analysis it is possible to meet this objective and establish that the impact on cost reduction is high and the impact on process productivity is very low.

Besides the impact on process productivity and costs the analysis proves that other benefits could be obtained. As discussed in section 2.2, regarding the facility layout objectives, the facilitation of the manufacturing process is an objective agreed by several authors. This objective is accomplished by the elimination of the backtracking problems of the current facility layout design. These backtracking problems could cause cross traffic between the processes and complicate the movement of the materials as well as the processes. Furthermore the elimination of backtracking problems would help to achieve another objective proposed in the literature review: employee safety. This is mainly because the cross traffic could cause collisions between the crane forks or accidents between the workers. In the company case study two problems regarding backtracking were identified. With the implementation of the plant layout alternative this problems are eliminated.

Another objective accomplished is the effective utilisation of the building cube. With the alternative 2 for plant layout factor it is possible to appreciate how the space is used more effectively and the processes are group together utilising a reduced space. This extra space could be use by the company for other purposes such as the implementation of the automatic stacking machine proposed. Although the automatic stacking machine does the same work of the six workers, this is a step towards a completely automatised production process that could avoid human mistakes.

However, this analysis could not prove some of the other objectives proposed in the literature. For example the objective of reduce inventories by improving the material handling factor could not be exposed by this analysis. This is because the work-in process in the plywood manufacturing is very hard to reduce because the veneers must have a long rest period after the log processing and the drying as explained in section 4.2.

With the results exposed that answer both the research question and its subsidiaries it is possible to summarise the key findings of this research. These are:

- Plant layout factor has a high impact over cost reduction but a very low impact over process productivity.
- Material handling factor has as well a high impact over cost reduction but a very low impact over process productivity.

- Material handling factor has a greater impact on both process productivity and cost reduction than plant layout factor. Therefore, it is the facility layout factor with the highest influence on facility layout design.
- The impact of facility layout design in cost reduction is high. Yet, the impact over process productivity is very low.

This research has contributed to the clarification and quantification of the impact of facility layout design over the process productivity and cost reduction. Moreover, it has established the individual contribution of its factors towards achieving these impacts. In addition, the discussion over the facility layout design objectives and the accomplishment of those was addressed.

CHAPTER 5: Conclusion

5.1 Introduction

The previous chapters have introduced the topic of facility layout design and its implication over the process productivity and costs. To do so, a theoretical framework was presented. This framework permitted an in- depth analysis of what have been said and studied in this subject. In addition, a case study was analysed that provided pragmatic evidence and a real comparison against the theory stated. Consequently the case study helped to provide reasonable results towards answering the research question proposed at the beginning of this study. Moreover, relevant recommendations to the case study company were established. This final chapter provides the conclusions of the research as well as the limitations of it and the implications for further research.

5.2 Conclusion

The focus of this research was to study the impact of facility layout design on the process productivity and costs. The study revealed that facility layout design has a greater impact on cost reduction than the impact on productivity. The key findings are listed below.

- Plant layout factor has a high impact over cost reduction but a very low impact over process productivity.
- Material handling factor has as well a high impact over cost reduction but a very low impact over process productivity.
- Material handling factor has a greater impact on both process productivity and cost reduction than plant layout factor. Therefore, it is the facility layout factor with the highest influence on facility layout design.
- The impact of facility layout design in cost reduction is high. Yet, the impact over process productivity is very low.

The costs reduction in the case study analysed could reach up to US$ 240,479. Regarding the individual contribution of the facility layout factors on cost reduction material handling factor proves to have the greatest impact with a cost saving of US$ 194,400 against the US$ 46,079 of flow factor. In terms of process productivity, material handling factor results revealed a 1.81% of improvement against the 0.42% of flow factor.

Besides the results for process productivity and cost reduction, this analysis proved other objectives that can be accomplished by a better facility layout design like employee safety and space utilisation.

In summary, the study revealed that material handling factor is responsible for the greatest individual contribution on process productivity and cost reduction. Moreover, facility layout design has proved to be an effective tool towards a better utilisation of the available resources. The next two sections discuss the limitations of this study and the implications for further research.

5.3 Limitations of this study

This section highlights some limitations regarding the study. This limitations affected different sections of this research. An important limitation was that a single case study was analysed. This influences directly on the results obtained because there is not another source of comparison. Moreover, the possibility to generalize the results is complex, and maybe the results would apply only to this case study.

In addition, the different interviewees could have been careful in the way to prevent different opinions regarding a specific topic discussed. This may have influenced on their opinions and therefore restricted this study. Also, the data analysed represent only a sample of the company and maybe the information is not entirely representative.

5.4 Implication for further research

This study constitutes just a small part towards revealing the impact of facility layout design in a company. There is much more to improve and learn about the implications of this subject. As explained in the analysis, the facility layout design is unique to every company so the possibilities for improvement are endless and could come from other companies and perhaps other industries. Thus, facility layout designers should not only focus on their company but also embrace different improvements from other companies. Hopefully the incorporation of different practices could provide a more comprehensive and representative view regarding facility layout design and its impact. Therefore, the research of more case studies will constitute a primary source of evidence in the task of clarifying the impact of facility layout design.

CHAPTER 6: REFERENCES

Apple, J. M. (1977). *Plant Layout and Material Handling.* (3rd Edition). New York: John Wiley &Sons.

Bryman, A. (1988). *Quantity and Quality in Social Research* .London: Unwin Hyman.

Caballero, R. J., Farhi, E., Gourinchas, P. (2008).*Brookings Papers on Economic Activity*. 1 (1), pp. 1-55.

Chien, T. (2004). 'An Empirical Study of Facility Layout using a modified SLP Procedure'. *Journal of Manufacturing Technology Management.*15 (6), pp. 455-465.

Cooper, D. R., Schindler, P. (2008).*Business Research Methods.*(10th Edition). New York: McGraw-Hill Higher Education.

Drira, A., Pierreval, H., Hajri-Gabouj, S.. (2007). 'Facility Layout Problems: a Survey'. *Annual Reviews in Control*. 31 (1), pp. 255-267.

Edward B. Mueller Company. Available at: http://www.muellerco.com/mueller_industrial_equipment_panel_stackers.asp. Last accessed 23 Sep 2009.

Eisenhardt, K. (1989). 'Building Theories from Case Study Research'. *Academy of Management Review.* 14 (4), pp. 532-550.

Erdogmus, H., Favaro, J., Strigel, W. (2004). 'Return on Investment'.*IEEE Software*. 1 (1), pp. 1-5.

Francis, R. L., McGinnis, L. F., White, J. A. (1992). *Facility Layout and Location: an Analytical Approach.*(2nd Edition). New Jersey: Prentice Hall.

Frazelle, E. H. (1986). 'Material Handling: A Technology for Industrial Competitiveness'. *Material Handling Research Center Technical Report.* Georgia Institute of Technology.

Fuller, B. (2009). *A record year for the global forest products industry?.* Available: http://www.lignumamerica.com/en/main/get/467. Last accessed 13 Jul 2009.

Heizer, J., Render, B. (2008). *Operations Management.* (9th Edition). New Jersey: Pearson Prentice Hall.

Hofstrand, D. (2006). *Don Hofstrand Understanding Profitability.* Available: http://www.extension.iastate.edu/agdm/wholefarm/html/c3-24.html. Last accessed 23 Jul 2009.

INFOR. (2008). *Mercado Forestal Nº33.* Available: http://www.infor.cl/estadisticas_mercado/mercado_forestal/mercadoforestal33.pdf. Last accessed 22 Jul 2009.

Kaplan R. S., Cooper R. (1997). *Cost and Effect: Using Integrated Cost Systems to Drive Profitability and Performance.*(1st Edition). Harvard: Harvard Business School Press.

Lamprecht, J. W. (1982). 'Building Blocks for Productivity Cranes, Hoists and Monorails'. *Material handling institute.*

Lignum. (2008). *Exportaciones a Estados Unidos caen 12,6% en primer semester por crisis subprime.* Available: http://www.lignum.cl/noticias/?id=12805. Last accessed 22 Jul 2009.

McEwan, E. K. (2000). The Principals Guide to Raising Mathematics Achievement.

Meller, R. D., Gau, K. (1996). 'The Facility Layout Problem: Recent and Emerging Trends and Perspectives'. *Journal of Manufacturing Systems*. 15 (5), pp. 351-366.

Meyers, F.E., Stephens, M.P. (2005). *Manufacturing Facilities Design and Material Handling.* (3rd Edition). New Jersey: Pearson Prentice Hall.

Muther, R. (1973). *Systematic Layout Planning.*(2nd Edition). Boston: Cahners Books.

Natural Resources Canada. (2008). *Hitting home—Impacts of the US housing crisis.* Available: http://canadaforests.nrcan.gc.ca/articletopic/184. Last accessed 22 Jul 2009.

Reed, R. Jr. (1961). *Plant Layout: Factors, Principles and Techniques.*(1st Edition). Illinois: Richard D. Irwin.

Rushton, A., Oxley, J., Croucher, P (2001). *The Handbook of Logistics and Distribution Management.*(2nd Edition).xx: Kogan Page.

Sarin, S. C., Loharjun P., Malmborg, C. J., Krishnakumar, B. (1992). 'A Multi attribute Decision-Theoretic Approach for the Layout Design Problem'. *European Journal of Operational Research.* 57 (1), pp. 231-242.

Slack, N., Chambers, S., Johnston, R. (2004).*Operations Management.*(4th Edtition). London: FT Prentice Hall.

Spelter, H., McKeever, D., Alderman M. (2006). 'Status and Trends: Profile of Structural Panels in the United States and Canada. Research Note FPL-RP-636'.*U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.* 1 (1), pp. 1-45.

Sthahl, J.F. (1990). 'Facility Productivity Today can be Planned, Measured and Controlled – do it'. *Industrial Engineering.*

Stoecker, R (1991), 'Evaluating and rethinking the case study', The Sociological Review, Vol. 39, pp. 88-112.

Sule, D. R. (2009).*Manufacturing Facilities: Location, Planning, and Design. (*3rd Edition). Boca Raton, FL: CRC Press.

Tanchoco, J. M. A. (1983). 'Unit Load Design: A Key Element in Integrating Material Movement and Storage'. *MHI Advanced Institute for Material Handling Teachers.* Auburn University, pp. 45-52.

Tompkins, J.A., White, J.A., Bozer, Y.A., Tanchoco, J.M.A. (2003). *Facilities Planning.* (3rd Edition). Hoboken, N.J.: John Wiley & Sons,Inc.

Van Maanen, J. (1983). *Qualitative Methodology.* (1st Edition). Beverly Hills: Sage.

Yin, R. K. (2009). *Case Study Research: Design and Methods.* (4th Edition). London: Sage Publications.

CHAPTER 7: APPENDICES

7.1 Appendix 1

Mathematical algorithms

CRAFT (Computerized Relative Allocation of Facilities Technique): developed by Armour and Buffa is an improvement-type algorithm. Meaning by this is that it works over an established layout. First, it determines the centroids of each department. Then, the algorithm evaluates exchanges of the centroids of nonfixed departments that are adjacent or equal in area. Finally, for each exchange the cost reduction is calculated and the largest one is chosen (Meller and Gau, 1996).

MULTIPLE (MULTI-floor Plant Layout Evaluation): developed by Bozer, Meller and Erlebacher it is similar to CRAFT because it uses an identical objective function (distance-based) and measures the distances between centroids. However, the difference among them is that MULTIPLE can exchange departments even though they are not adjacent (Tompkins *et al.*, 2003).

LOGIC (Layout Optimization with Guillotine Induce Cuts): developed by Kar Yan Tam this algorithm performs several horizontal and vertical cuts over the layout structure. For example, after a vertical cut the subset of departments generated is arranged either to the east or west side of the cut. If the cut is horizontal, the departments are arranged to the north or south of the cut.

SHAPE: developed by Hassan, Hogg and Smith is a construction algorithm. Therefore it creates a completely new layout. It uses a discrete representation and an objective that is based on rectilinear distances among the department's centroids (Meller and Gau, 1996). A discrete representation allows the computer to work the layout as a matrix (Tompkins *et al.*, 2003). The department allocation is based on a ranking, which considers the amount of flow of a department and a critical flow value defined by the user (Meller and Gau, 1996).

Software packages

FactoryOPT: developed by CIMTECHNOLOGIE this software is based on the SPIRAL algorithm as well as in the CRAFT algorithm. SPIRAL algorithm was created by Marc Goetschalckx and it works by quantifying the relationship between the departments. This relationships then are presented in an adjacency graph and furthermore in a block layout (Meller and Gau, 1996).

Factory Modeler: developed by Systéms Espace Temps Inc. is based on the MIP algorithm. This algorithm, developed by Montreuil, is a mixed-integer programming formulation. The algorithm uses a distance-based objective function, but in contrast to other algorithms this one uses the continuous layout representation (Meller and Gau, 1996). A continuous layout representation it is not restrained to an underlying grid structure and is more flexible than a discrete representation where a structure must be taken into consideration (Tompkins *et al.*, 2003).

SPIRAL: this package is distributed by Marc Goetschalckx and it is based on the SPIRAL algorithm presented earlier with some other further improvements options (Meller and Gau, 1996).

7.2 Appendix 2

Interview Subject: **Data of interview:** **Name of the company:** **Name of the interviewed:** **Position on the company:**
1. In your opinion, which are the main processes in the plywood manufacturing? 2. Do you think that facility layout design could have a relevant impact on the productivity and cost reduction of the company? Why? 3. What is your opinion about flow backtracking problems? Do you have any? 4. Do you have a flow pattern or the layout design was developed over other considerations?

5. There are several processes involved in the manufacturing of plywood. Could you relate this processes with the activity relationship scale (shown to the interviewee) between:
   - Log processing
   - Log conditioning
   - Lathing
   - Clipping
   - Drying
   - Jointing
   - Gluing and assembly
   - Press
   - Dimensional cutting or trimming
   - Repairing
   - Sanding

6. In your opinion, which of the following reasons for closeness between departments are the relevant ones and in which order would you establish them?

Code	REASON
1	Flow of material
2	Ease of supervision
3	Common personnel
4	Contact necessary
5	Convenience

7. There are two main costs in the transportation of materials: the personnel involved and the equipment. Which do you think is more relevant in the processes mentioned? Why?

8. What size of unit load do you currently use in the manufacturing process? Do you have more than one size of unit loads?

9. How many workers are assigned only to material handling aspects and how many workers are in the entire manufacturing process?

10. The storage area is in the same place that the manufacturing process, do you think this is a disadvantage?

11. The greatest amount of work-in progress is currently located on the side of the drying process, is this a restriction or it is the only available place to deal with work-in progress?

12. The plywood manufacturing process, as any wood process, leaves a large amount of dust in the air and residuals of wood in the floor, does this waste have a negative effect on your product and does it affect any other relevant issues?

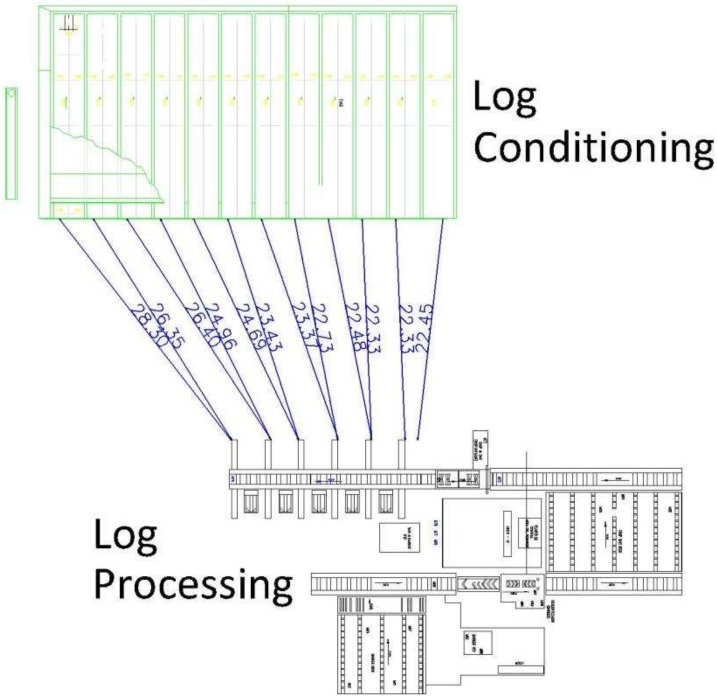
13. Which of the current processes can be rearranged without any problems? Is it feasible

to move the other processes? What is the cost of moving them?

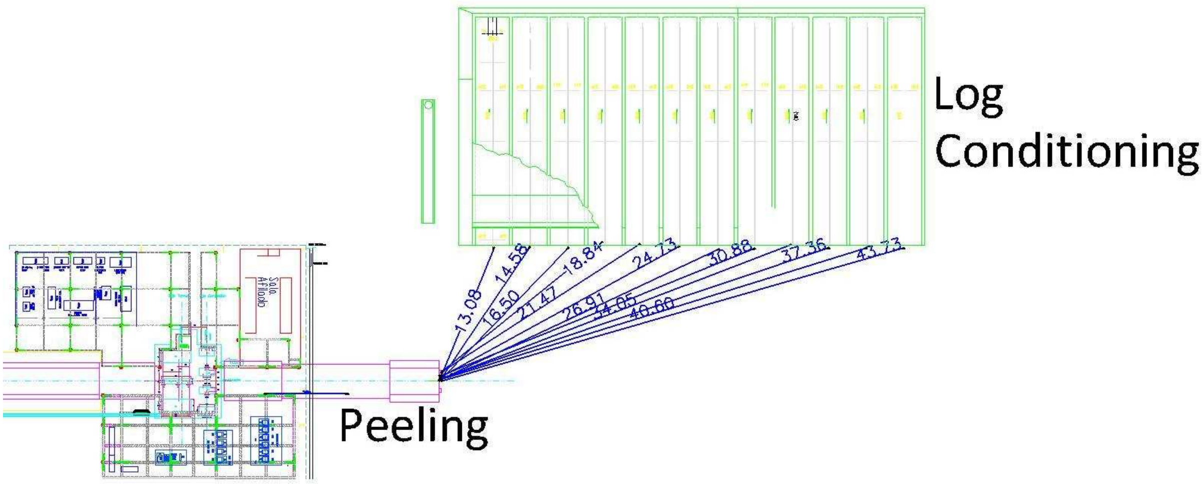
7.3 Appendix 3

Distances between processes of Current Layout Design

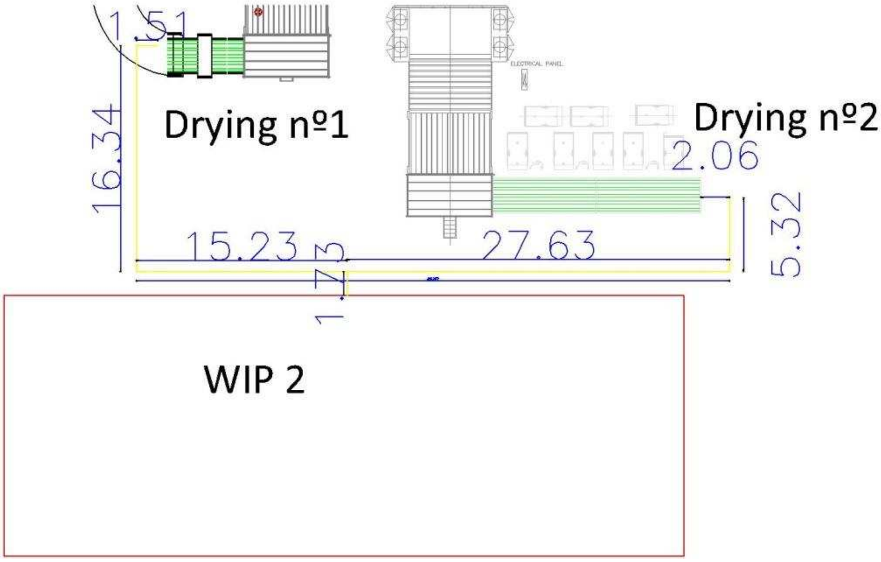
Log Processing – Log Conditioning



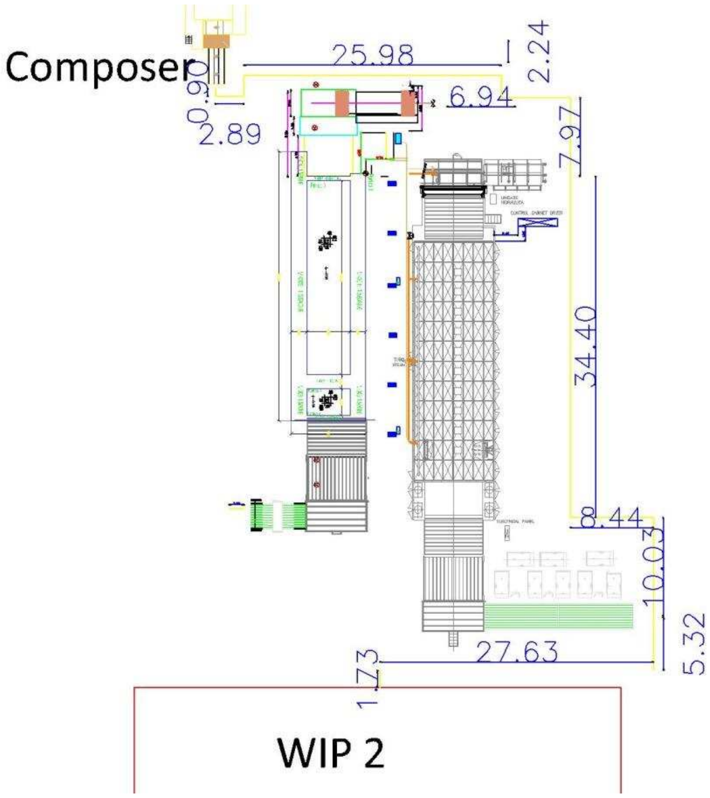
Log Conditioning – Peeling



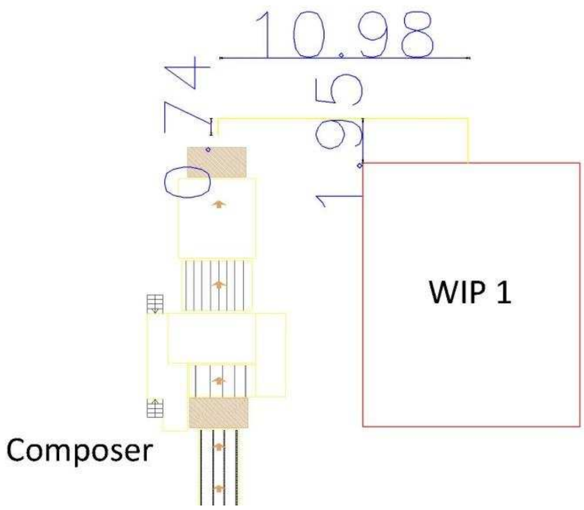
Drying – Work-in process area 2



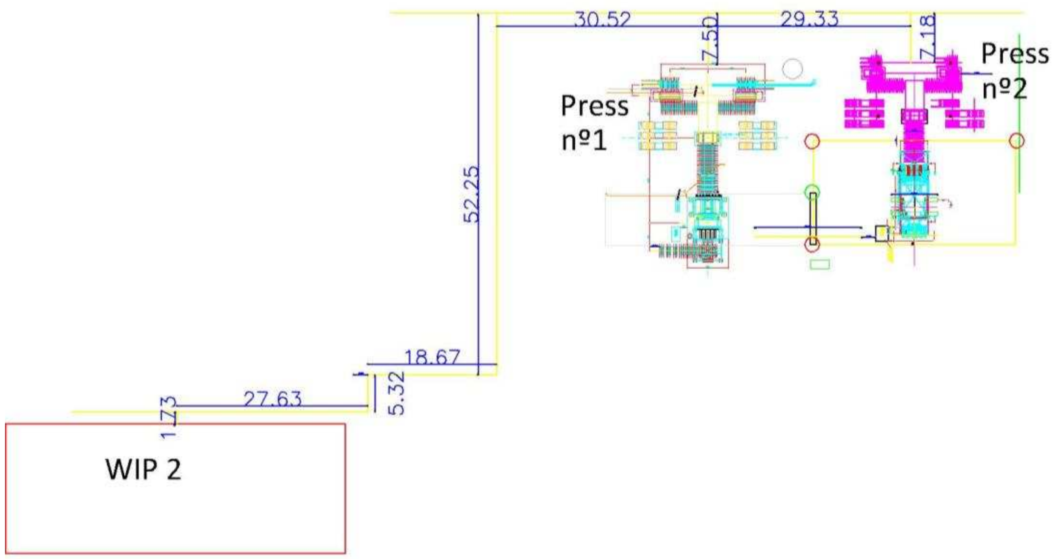
Work-in process area 2 – Composer



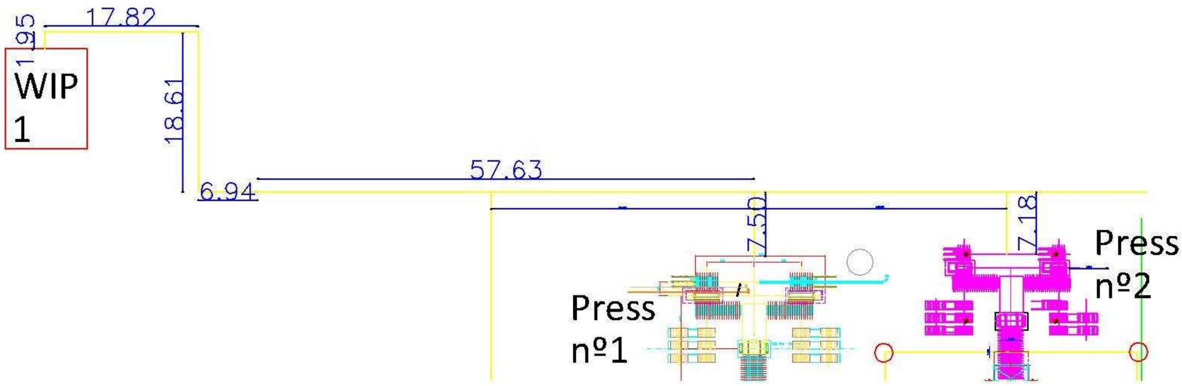
Composer – Work-in process area 1



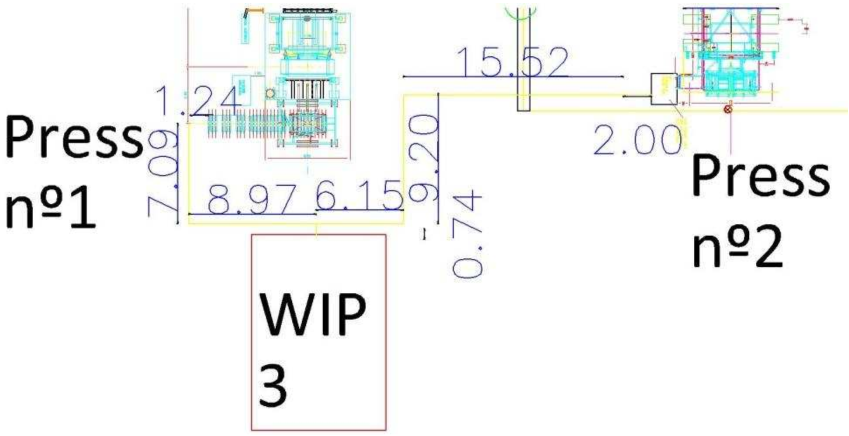
Work-in process area 2 – Press



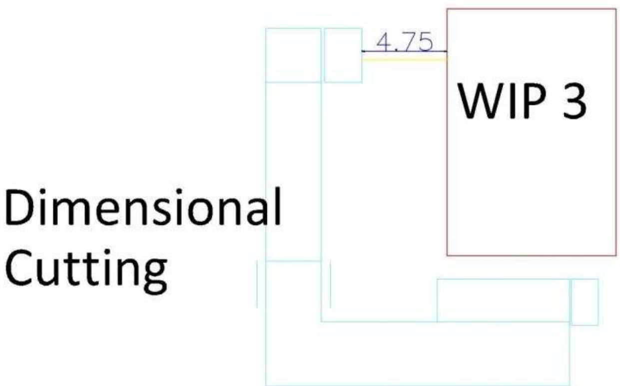
Work-in process area 1 – Press



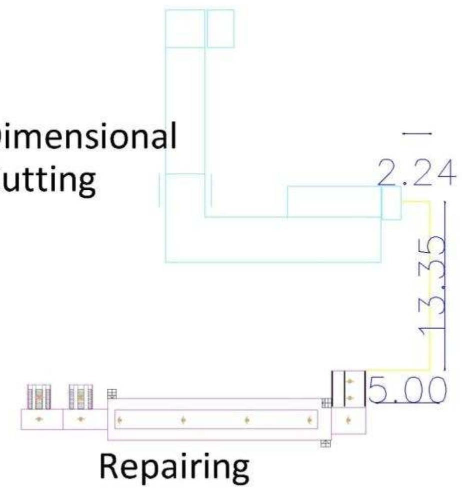
Press – Work-in process area 3



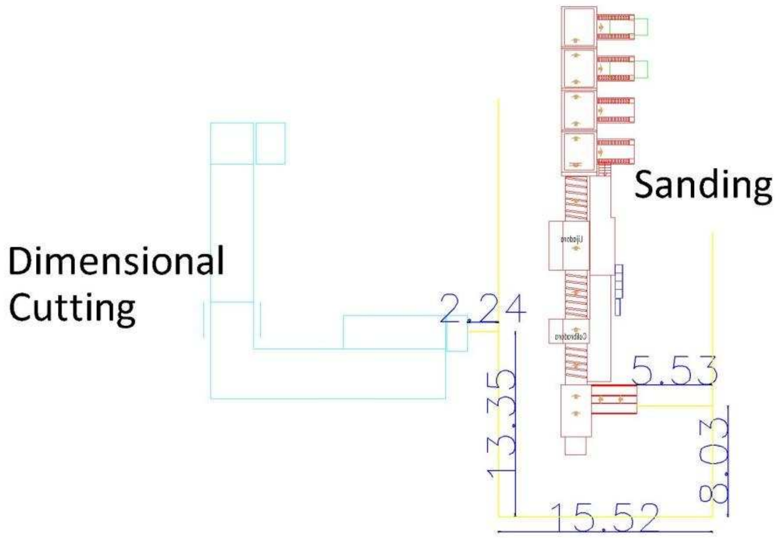
Work-in process area 3 – Dimensional cutting



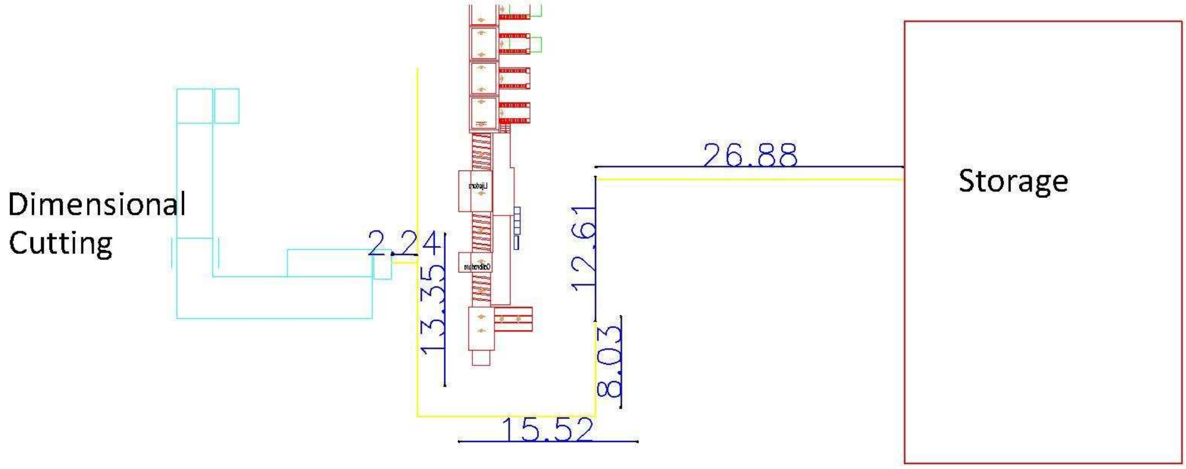
Dimensional cutting – Repairing



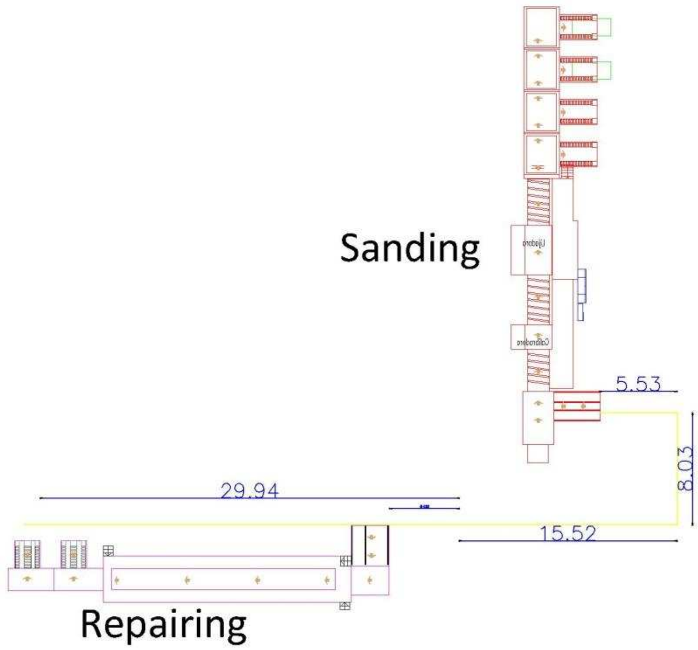
Dimensional cutting – Sanding



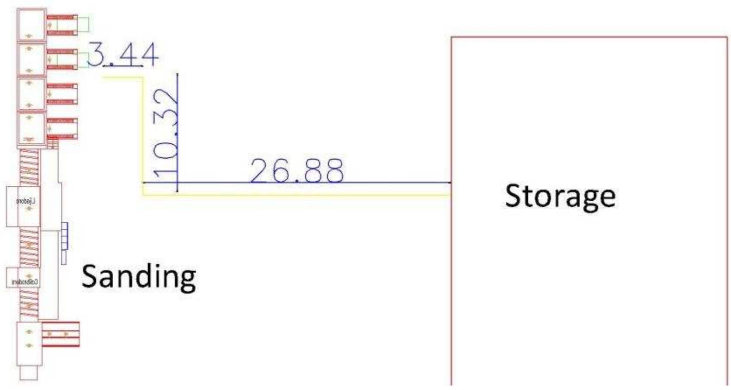
Dimensional cutting – Storage



Repairing – Sanding



Sanding – Storage



7.4 Appendix 4

Production summary

URUPANEL

Control de Producción

Volver

INDICADORES - PREPARACION DE MADERA

		Julio	Agosto	Setiembre	Octubre	Noviembre	Diciembre	Ene-09	Feb-09	Mar-09	Abr-09	May-09	Jun-09	Jul-09
Pino	Stock Objetivo	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
	Stock Total	1241	410	6963	8303	10208	7932	5102	9286	4614	8781	1465	0	0
	Recepción	10846	12381	17481	16044	11828	4749	9239	13835	7699	5050	7089	7679	6582
	Cunsumo	12725	13211	10928	14705	9923	7023	12071	11650	12371	6155	9133	9144	5839
Euca	Stock Objetivo	200	200	200	200	200	200	200	200	200	200	200	200	200
	Stock	0	0	0	0	0	0	0	0	0	0	0	0	0
	Recepción	3620	2153	3223	1588	4188	456	2581	2299	3829	2763	4571	4651	3699
	Cunsumo	3620	2153	3223	1588	4188	456	2581	2299	3829	2763	4571	4651	3699
Pino	Rango													
	21-25	65%	74%	82%	88%	84%	92%	66%	62%	81%	95%	100%	99%	88%
	25-29	13%	8%	11%	11%	14%	8%	32%	30%	14%	5%		1%	12%
	29-33	21%	18%	7%	1%	1%		1%	7%	4%				
	33-38	1%						0%	1%	0%				
	Rend	60,4%	58,4%	57,3%	55,2%	59,9%	57,7%	58%	55%	55%	48%	48%	56%	53%

URUPANEL

Control de Producción

Volver

INDICADORES - DEBOBINADO

		Junio	Julio	Agosto	Setiembre	Octubre	Noviembre	Diciembre	Ene-09	Feb-09	Mar-09	Abr-09	May-09	Jun-09	Jul-09
Pino	Rendimiento	63%	60%	58%	57%	55%	60%	58%	58%	55%	55%	48%	46%	56%	55%
	Diám Prom	28,9	25,7	25,4	24,4	23,8	23,9	24,3	25,5	25,5	24,6	23,6	22,8	22,6	24,3
Euca	Rendimiento	55%	53%	50%	44%	40%	51%	60%	58%	54%	52%	56%	52%	53%	51%
	Diám Prom	24,4	24	24,4	24,1	24,1	23,9	23,5	25,9	25,5	25,6	25,2	24,4	24,5	24,7
Total	Rendimiento	61%	59%	57%	54%	55%	57%	58%	58%	55%	54%	50%	48%	55%	53%
	Diám Prom	27,8	26,4	26,27	24,4	23,8	23,9	24,2	25,6	25,5	24,7	24,1	23,2	23,24	24,4
	%FS	83,0%	82,8%	81,1%	76,8%	77,4%	79,5%	79,5%	81%	78%	79%	76%	75%	79%	78%
	%RW	16,2%	16,3%	17,9%	22,0%	21,2%	19,8%	19,6%	18%	21%	21%	24%	25%	20%	21%
	%FT	0,8%	0,9%	1,0%	1,2%	1,4%	0,7%	0,9%	0,7%	1,0%	0,5%	0%	0%	0%	0%
	Producción	8762	9741	8991	7628	8680	7678	4784	7896	7655	9056	4178	6274	7529	9642

	mes	T-Total	Tmuertos	T-Efectivo	Disponibilidad	Producción	Prom. Diario	Ritmo
Ritmo Dep.		Min	Min	Min	%	m3	m3/día	m3/h
	Noviembre	36960	12876	24084	65%	7678	274	19
	Diciembre	21600	7263	14337	66%	4783	319	20
	Ene-09	33120	13355	19765	60%	7896	343	24
	Feb-09	34080	13205	20875	61%	7655	284	22
	Mar-09	38880	13074	25806	66%	9056	291	21
	Abr-09	21600	7997	13603	63%	4178	280	18
	May-09	28800	11168	17632	61%	6274	273	21
	Jun-09	32160	11133	21027	65%	7529	327	21
	Jul-09	30240	16398	13842	46%	5080	242	22

Control de Producción

URUPANEL

Volver

INDICADORES - SECADORES

		Julio	Agosto	Setiembre	Octubre	Noviembre	Diciembre	Ene-09	Feb-09	Mar-09	Abr-09	May-09	Jun-09	Jul-09
Omeco	Ttotal				43200	41760	27360	37440	39600	44640	21600	34560	25920	28800
	Tmuertos				5060	3819	2542	6629	4510	4447	3493	5146	6024	6739
	Tefectivo				38140	37941	24818	30811	35090	40193	18107	29414	19896	22061
	Disponibilidad				88%	91%	91%	82%	89%	90%	84%	85%	77%	77%
	Producción				5069	4447	2815	3887	4510	4967	2200	3436	3860	2668
	Prom. Diario	164,3	161,8	156,2	169	153,3	148,1	148,6	163,19	160,22	157	143,16	125	140,4
	Ritmo				8,0	7,0	6,8	7,6	7,7	7,4	7,3	7,0	11,6	7,3
88	Ttotal				43200	41760	27360	37440	38160	40800	21600	34560	25920	25592
	Tmuertos				8012	9314	6491	5279	8569	9966	5090	14960	7245	7315
	Tefectivo				35188	32446	20869	32161	29591	30834	16510	19600	18675	18277
	Disponibilidad				81%	78%	76%	86%	78%	76%	76%	57%	72%	71%
	Producción				3013	2848	1942	3115	3061	3366	1626	1921	2872	1724
	Prom. Diario	126,3	117,8	90,9	100,4	105,5	102,2	119,8	115	120,205	120,2	113,0	93,0	107,8
	Ritmo				5,1	5,3	5,6	5,8	6,2	6,5	5,9	5,9	9,2	5,7
Secador	Producción	8840	8464,5	7327,5	8082	7295	4757	7001,8	7571	8333	3826	5357	6732	4392
	Rendimiento	90%	89%	87%	89%	88%	87%	86%	88%	88%	89%	89%	88%	87%
	% Resecado	10%	11%	12%	14%	12%	12%	13%	12%	12%	10%	9%	8%	10%

	% Calidades Producidas							
	BP	c	c+	d	ft	hs	i	RW
Junio	7,0%	10%	9%	12%	2%		30%	31%
Julio	8,0%	10%	11%	10%	1%		34%	26%
Agosto	6,0%	7%	14%	12%	1%		31%	30%
Septiembre	5,0%	6%	14%	9%	1%		28%	36%
Octubre	6,0%	5%	15%	11%	1%		25%	37%
Noviembre	9,0%	4%	12%	5%			34%	36%
Diciembre	11,0%	2%	19%	2%	2%		31%	33%
Ene-09	8,0%	3%	21%	2%	1%		35%	30%
Feb-09	8,0%	2%	17%	5%	1%		34%	33%
Mar-09	7,6%	7%	16%	7%	1%		31%	32%
Abr-09	8,2%	8%	13%	4%	0%		32%	34%
May-09	6,7%	5%	16%	3%	0%		32%	37%
Jun-09	8,0%	5%	18%	5%	0%		35%	30%
Jul-09	8,9%	4%	7%	4%	0%		38%	28%

URUPANEL

Control de Producción

Volver

INDICADORES - PRENSA

		Julio	Agosto	Setiembre	Octubre	Noviembre	Diciembre	Ene-09	Feb-09	Mar-09	Abr-09	May-09	Jun-09	Jul-09
Producción		6735	6660	5502	6014	5024	3803	5222	5075	6437	3045	3557	4713	2257
Media Prensa		321	333	251	231	218	254	237	254	257	254	254	248	174
Prod. BC		1664,5	1427,6	1321,2	2795	1942	1542	2080	1132	583	399	1771	1325	1137
%BC		25%	21%	24%	46%	39%	41%	40%	22%	9%	13%	50%	28%	50%
Prod. No lijados		937,8	1517,4	1154,1	1070,1	893	173	444,13	603	2536	642,5	0	0	443,7
% No Lijados		14%	23%	21%	18%	18%	5%	9%	12%	39%	21%	0%	0%	20%
Cons. Especifico		71,6	74,1	67,2	68,2	76,1	71,7	70,5	67,6	66,0	70	72,5	76,8	79,4
	3	0%	3%	4%	3%	2%	2%			3%	6%		2%	20%
	4	0%	0%	0%	0%	0%	0%			14%				
	5	73%	78%	78%	72%	36%	57%	71%	73%	60%	75%	48%	49%	23%
	7	27%	19%	18%	25%	62%	41%	29%	27%	14%	19%	52%	49%	58%

URUPANEL

Control de Producción

INDICADORES - JUNTADORA

Volver

	Julio	Agosto	Setiembre	Octubre	Noviembre	Diciembre	Ene-09	Feb-09	Mar-09	Abr-09	May-09	Jun-09	Jul-09
Volumen	666	703	659	397	381	374	476	218	348	188	194	378	347

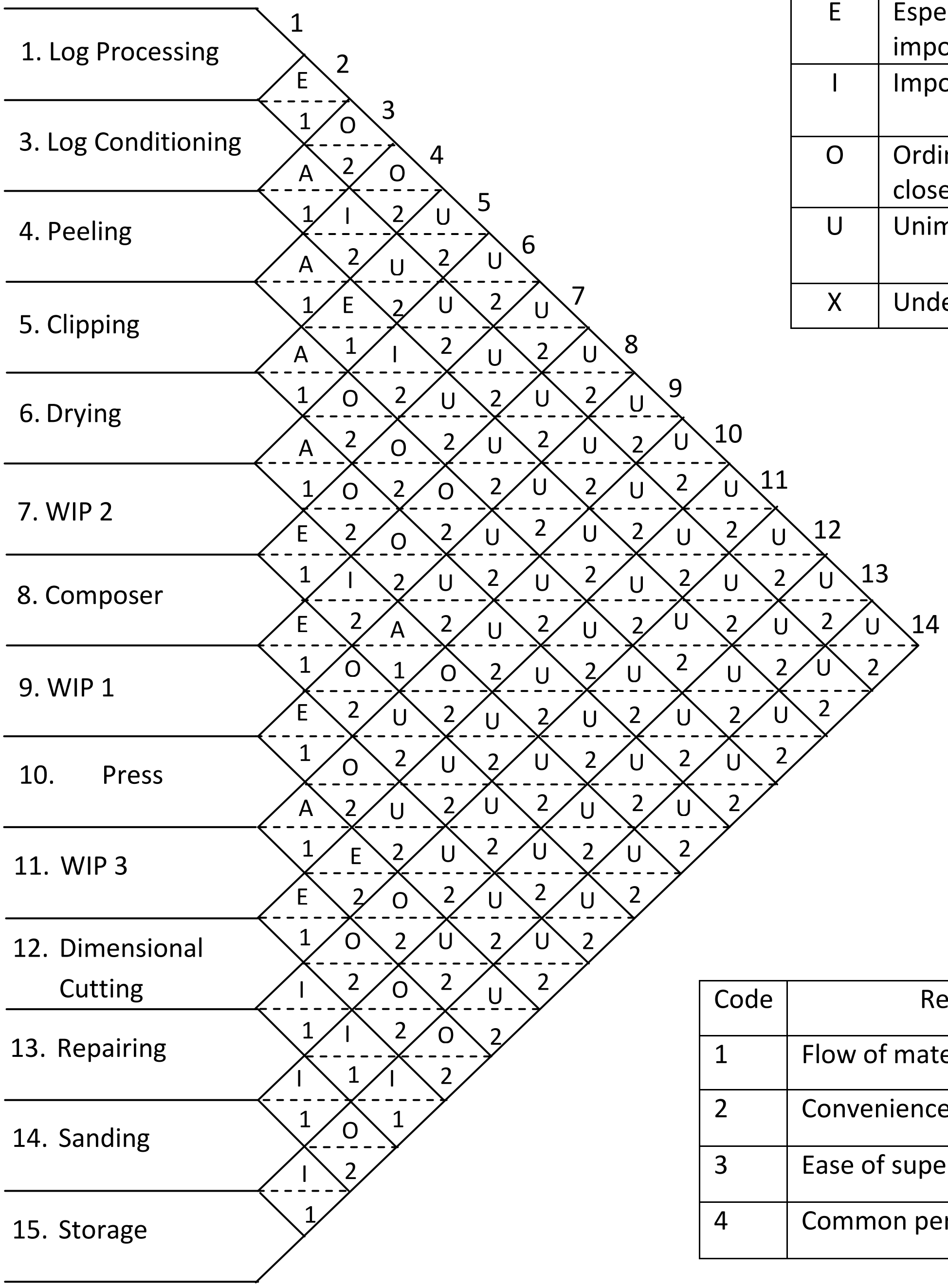
7.5 Appendix 5

Capital and labour inputs

			September		October		November		Dicember	
	Value	Unit	Consumption	Cost	Consumption	Cost	Consumption	Cost	Consumption	Cost
PRODUCTION IN M3			5600		6000		6500		6500	
PINE WOOD	28,5	US/m3	6079	173250	6632	189000	7184	204750	7184	204750
BASAL PINE WOOD	38	US/m3	4053	154000	4421	168000	4789	182000	4789	182000
EUCA WOOD	24	US/m3	4342	104211	4737	113684	5132	123158	5132	123158
Total Wood			14474	431461	15789	470684	17105	509908	17105	509908
Other Materials	425,55	USD/ton	385	163837	426	181284	468	219073	475	222116
Electric Energy	16	USD/m3		88000		96000		104000		104000
Packaging	4	USD/m3		42000		44000		46000		46000
Salaries				140400		140400		140400		140400
Maintenance				4000		4000		4000		4000

7.6 Appendix 6

Value	Closeness
A	Absolutely necessary
E	Especially important
I	Important
O	Ordinary closeness okay
U	Unimportant
X	Undesirable

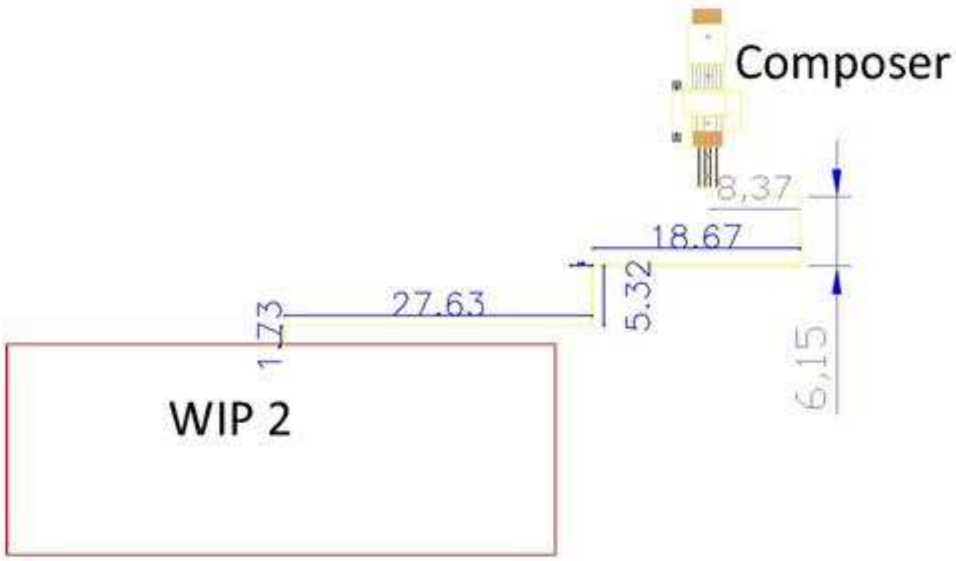


Code	Reason
1	Flow of material
2	Convenience
3	Ease of supervision
4	Common personal

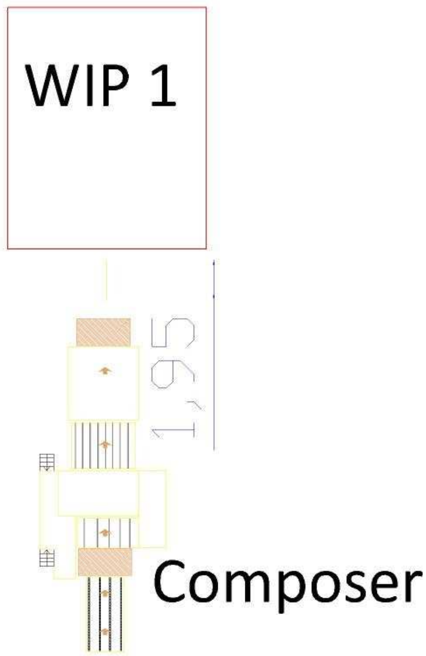
7.7 Appendix 7

Distances between processes of layout alternative 1

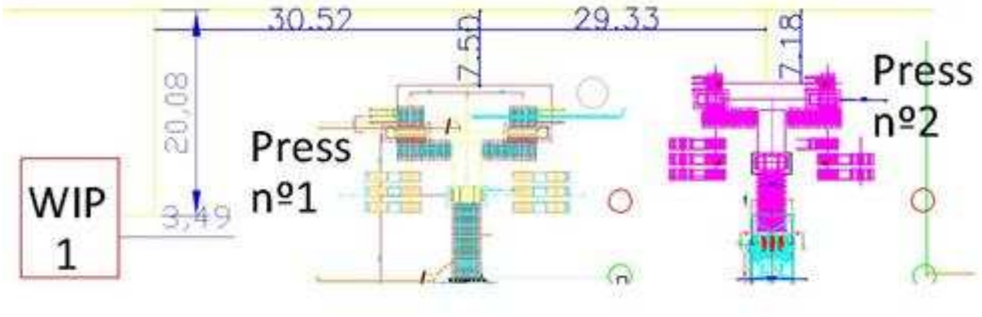
Work-in process area 2 – Composer



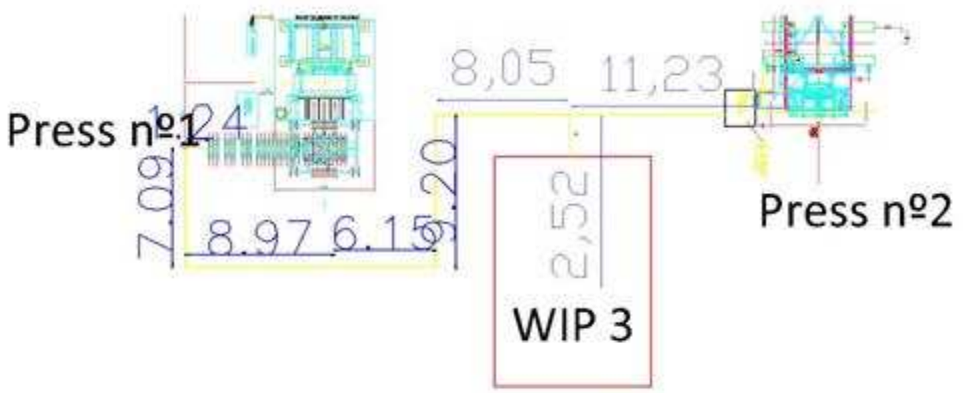
Composer – Work-in process area 1



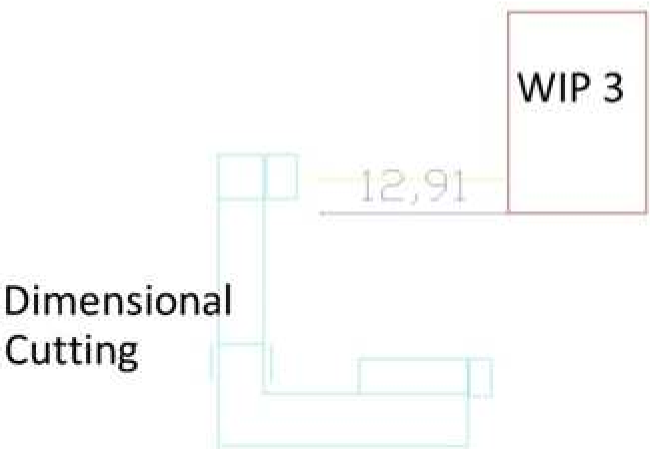
Work-in process area 1 – Press



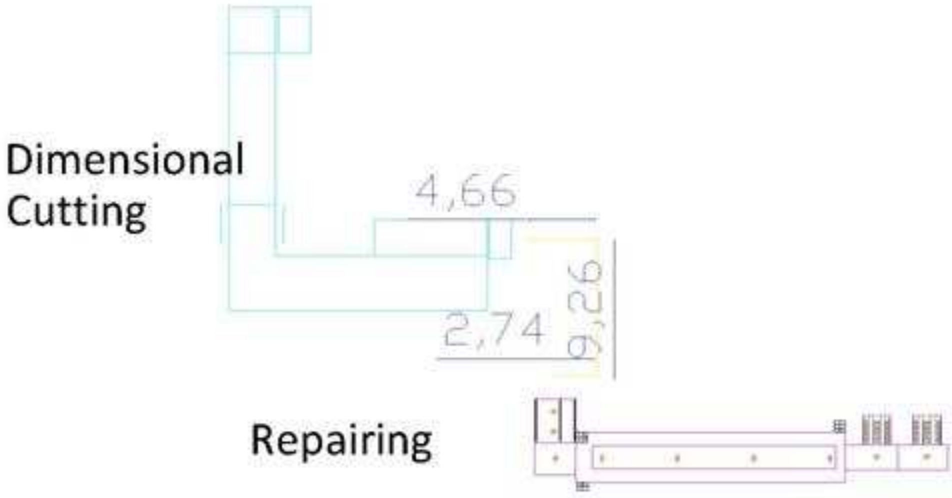
Press – Work-in process area 3



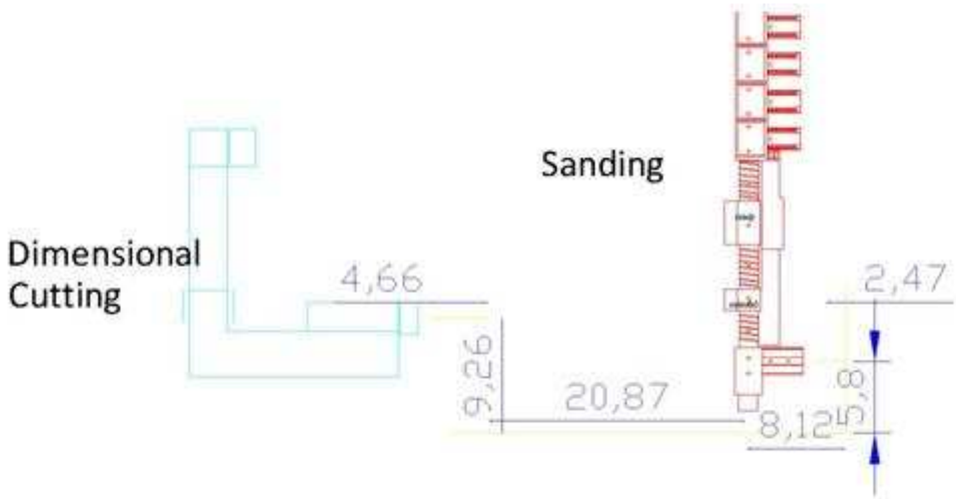
Work-in process area 3 – Dimensional cutting



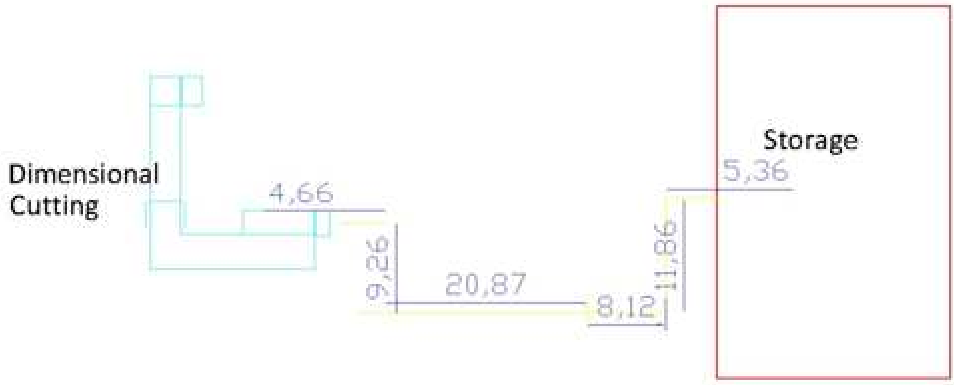
Dimensional cutting – Repairing



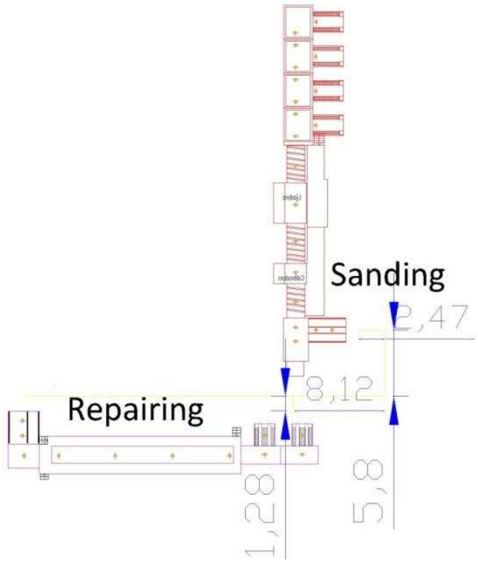
Dimensional cutting – Sanding



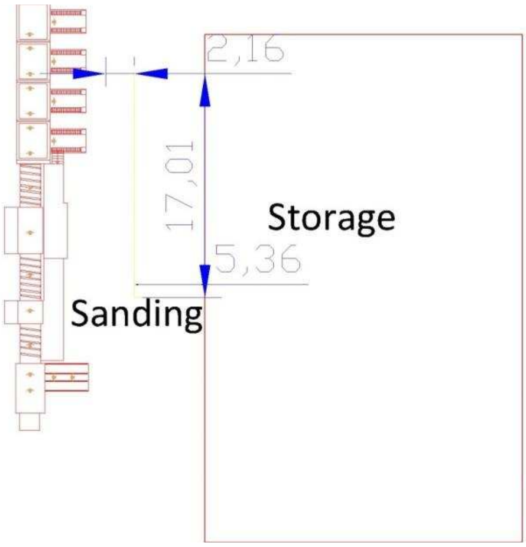
Dimensional cutting – Storage



Repairing – Sanding



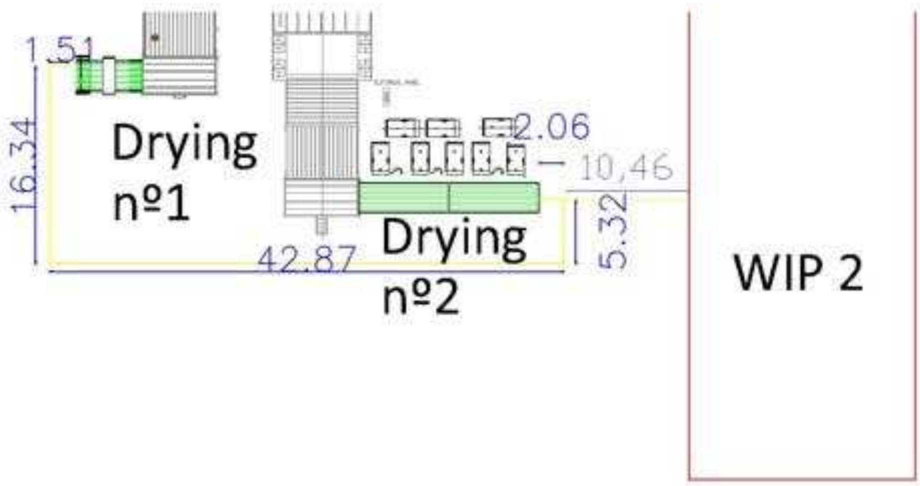
Sanding – Storage



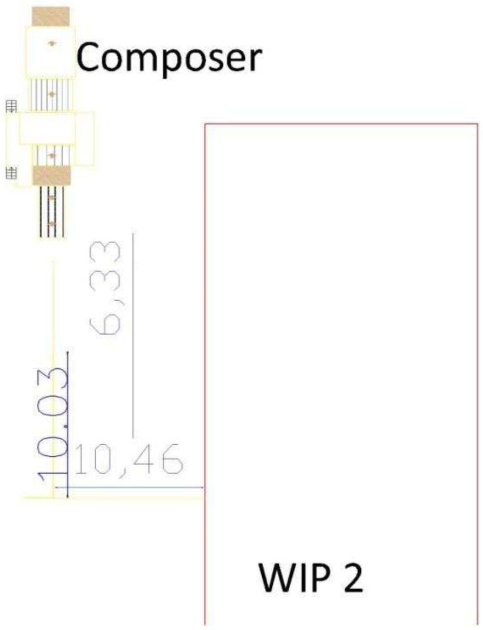
7.8 Appendix 8

Distances between processes of layout alternative 2

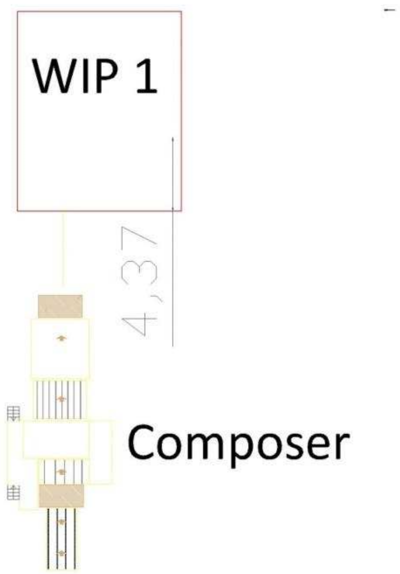
Drying – Work-in process area 2



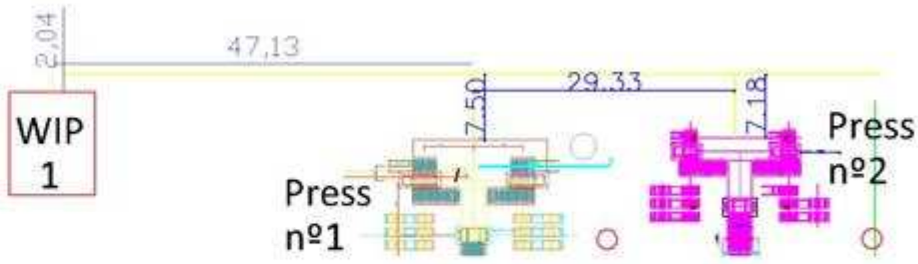
Work-in process 2 – Composer



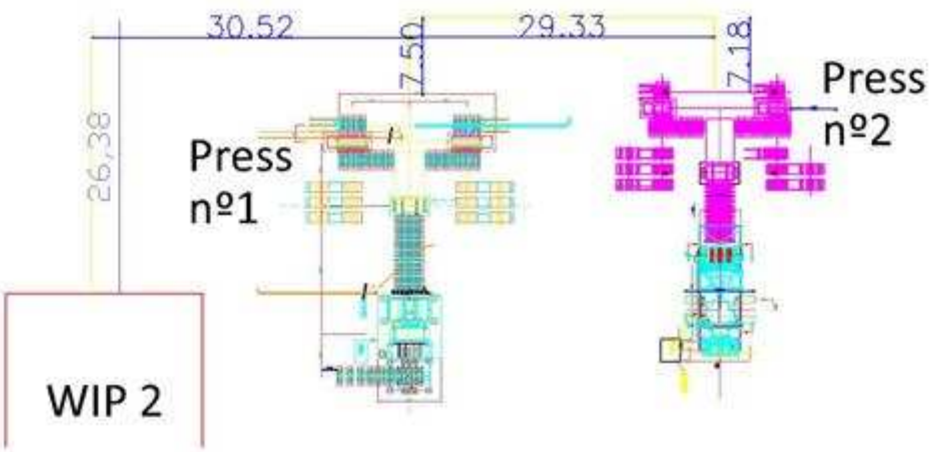
Composer – Work-in process area 1



Work-in process area 1 – Press



Work-in process area 2 – Press



7.9 Appendix 9

Storage areas available